ENDEAVOUR

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Science fiction

While popular exposition of the facts of science has achieved only a fluctuating and never very great following—though it is happily more fashionable now than it has been for a very long time—fiction with a scientific flavour has proved more acceptable and in recent years has gained a wide circle of readers. Indeed, in some countries science fiction seems to be displacing in popularity the crime story which has held first place for decades. On the generally acceptable premise that the public at large ought to know something of the progress of science and the part it may play in daily life, this development should meet with general approval, for as the sugared pill is the most palatable medium for medicine, so fact becomes more eagerly assimilated if attractively presented and seasoned with adventure, romance, and the other stock ingredients of fiction.

Fiction can undoubtedly be an important medium for the wide dissemination of scientific ideas. A necessary proviso, however, is that it should not only aspire to a reasonable literary standard but should be technically sound so far as matters of fact are concerned. Unhappily, it is very clear that, with a few praiseworthy exceptions, neither of these conditions is today being fulfilled or even sought. Much modern science fiction is badly written, inaccurate, and unbalanced in the sense of showing marked predilection for space travel; important and interesting though the latter may be, it is far from being the principal goal of modern science. It is clear that many authors and their publishers are profitably availing themselves of a change in public taste, without regard to—or probably consciousness of—the unfortunate consequences which may result.

Particularly unfortunate is the widespread introduction of what purports to be science into the very lowest forms of popular literature, where the twin themes of sex and violence have hitherto been deemed sufficient to satisfy the most demanding reader. Now, however, the vocabulary of science has been ransacked in an attempt to give an air of novelty to a well worn topic. The villain, who has always kept himself in the van of progress, now spurns even the most efficient of automatic weapons in favour of meson-guns; he maintains contact with his confederates by supersonic radio; and in his rare moments of relaxation dallies with his women in the comfortable shelter of a network of death-rays. There is, nevertheless, a crumb of comfort to be gained even here, for the forces of good ultimately outwit those of evil by means of some even more dramatic application of pseudo-science.

Without attributing undue importance to it—and scientists as a class are perhaps inclined to take themselves over-seriously—the present situation ought not to be looked upon with indifference. At a time when research is inevitably being financed more and more from public funds it is correspondingly important to have the goodwill of the public itself. While it is axiomatic that no layman can have any profound knowledge of science as a whole, or even of any branch of it—in that he would then be considered to have graduated from the laity and entered the ranks of scientists—it is certainly desirable that he should not acquire a wholly false picture of scientists, their aims and ideals, and the results of their work. In one important respect bad science fiction can be very much more harmful than bad exposition of scientific fact: it deals with the scientist personally rather than professionally. To be constantly portrayed as curious in appearance and eccentric in habit, irresponsible in action and heartless in behaviour, and—in general—as belonging to a class apart, does nobody any good. Unless effectively countered by responsible writing, the sensational science fiction of today may have a cumulatively damaging effect upon public appreciation of both science and scientists.

Science, as it presents itself in its own journals, seems to be a wholly logical process, one experiment suggesting another and leading ultimately to a unifying explanation. Experience, however, shows that it is often the shot in the dark, the inspired guess confirmed later, that is of critical importance. Far from being the slave of fact and logic so often portrayed, the scientist profits greatly from a fertile imagination, and should be the last to deplore the same gift in the writer of fiction. Imaginative, yet informed, science fiction should be not merely tolerated but encouraged, for from it important ideas may stem. What is desirable, however, is that imagination should be restrained, and not applied in fields where fact is firmly established. Science fiction may well venture beyond the frontiers of knowledge, yet within those frontiers should acknowledge their existence.

Why, it may be asked, has science inspired so little literary work of real merit in spite of the

great popularity of science fiction in recent years? Clearly no single factor can be held responsible, nor can all the factors involved be discerned; nevertheless, it is possible to see some of the main reasons. Scientific and literary ability are both rare and are not commonly encountered in the same individual. On purely statistical grounds, therefore, one would anticipate that those equipped to write good science fiction would be few and far between, and experience certainly bears this out. Moreover, talent is not always exploited even where it exists; not unnaturally, scientists with a taste for writing often prefer to find their outlet in themes far removed from their daily work. It would be foolish to deprecate this preference, for it must surely seem desirable that the discipline of deductive reasoning—in which scientists, in their own estimation at least, are proficient—should be applied to as many fields of human endeavour as possible. The able professional writer finds plenty to occupy him without the trouble of acquiring a scientific education, to which, despite claims to the contrary, there is no short cut. The result is that there are few indeed in a position adequately to meet the demand, and so the field of science fiction has become largely the preserve of the ill-informed sensationalist.

Thus the problem of science fiction clearly lies not in the raw material—for the facts of science and their potential consequences rival the fantasies of fiction—but in the writers. Many scientists have shown considerable flair for explaining science to laymen, but have not ventured into the adjacent field of fiction, perhaps because the exposition of fact comes readily to them, whereas the recounting of fiction needs, apart from differences in technique, the suppression of certain professional inhibitions. Nevertheless, the step seems not to be a great one, and it is much to be hoped that, in the interests of both themselves and their profession, some scientists accustomed to explaining facts simply will try the experiment of doing so within a fictional framework.

Unfortunate though it is, the present situation is certainly not hopeless, for the works of such men as H. G. Wells and Jules Verne are proof that science and literature are not incompatible. While these were admittedly writers of an earlier generation, when science was much less complex than it is now, there seems no good reason why similar standards should not be attained today. Science in fiction generally depends upon principle rather than detail; although many new principles have been, and are constantly being, introduced, their understanding and exposition need not be very difficult.

Science fiction if well done should benefit the cause of science as a whole, and while some attempts may prove a literary failure they are unlikely to do positive harm. The unqualified science writer is, however, a difficult problem. It would be both unjust and unreasonable to seek to discourage him, and to look upon all forms of science writing as strictly the preserve of scientists, for some of the best expositors of science today have had no formal training. The important thing is for the writer to know his limitations, to rely on himself only up to the limits of his own knowledge and thereafter to seek expert advice, which should not be withheld. This guiding principle is followed by the few, but there remain those who make no attempt to confine themselves to either truth or probability. With such there is no reasoning, and doubtless they will be always with us, but their numbers and influence can be limited by ensuring a satisfactory flow of better material. It is undeniable that there is a strong public appetite for science fiction, and if it cannot feed upon the good it will swallow the bad; only a sufficiency of good fare will make the other unpalatable.

Science has become an important—indeed, a dominant—factor in daily life, and a literature which either ignores it or grossly distorts it is clearly unbalanced, for the task of literature is to portray life in all its aspects. While it would be unfortunate if a sense of proportion were lost and writers cultivated science too intensively or too seriously, it is obviously desirable that the balance should be redressed. For this to be achieved, however, scientists must themselves take the lead, both by protesting against the misleading and sensational and by supporting the good. They have, too, an essential part to play by making themselves more accessible to the serious inquirer, and it will be a happy circumstance when the importance of this role is more widely recognized. In return for such assistance from scientists, however, writers must scrupulously respect the frequent professional need of the scientist for anonymity, and here the indiscretions of the few can be prejudicial to the many. Some recent novels, for example, have—despite a change of name—clearly identified particular laboratories, to the embarrassment and annoyance of those working in them. While such lapses of taste are fortunately rare, their occurrence is regrettable as being inimical to the establishment of good relations between scientists and writers.

High-voltage spark discharges

F. M. BRUCE

The development of high-voltage impulse generators and recording techniques has enabled investigations of the mechanism of the electric spark in air to be made in minute detail—in fact, to time-intervals of the order of a microsecond or even less. Spark theory has been advanced, and spark-gap characteristics have been studied as a method of measuring voltage and for elucidating the breakdown mechanism. For both purposes electrode profiles confining the gap to a region of uniform field strength are better than the familiar sphere gap.

SPARK DISCHARGES IN ELECTRICAL ENGINEERING

The sudden, and at times spectacular, appearance of an electric spark in the air gap between two electrodes was familiar to scientists for many years before the physical nature of the phenomenon could be investigated or to any extent understood. Spark discharges could be obtained from Leyden jars, from Wimshurst machines, and from induction coils. Similarities between lightning discharges and the electric sparks from Leyden jars led Franklin in 1752 to make the famous experiment [1] that proved the relationship. His experiments led him to the successful application of the principles of protection by earthed conductors, but this empirical work preceded relevant theoretical knowledge by more than 150 years.

At the beginning of the present century, electrical engineers used the transformer to develop systems for the transmission of electrical energy at high A.C. voltages. For any given transmission system there is a preferred voltage, which is determined by the energy to be transmitted, the distances involved, and economic considerations [2]. The ever growing demand for electrical energy led to an increase in operating voltages up to the present level of 380 kV; much higher voltages became available for research and test purposes. Testing-transformers, connected in cascade, have made available voltages of 1000 kV and more at power frequencies, but it is also necessary to test high-voltage equipment under conditions representing the over-voltages due to lightning disturbances on lines and connected equipment. Impulse generators [3], comprising a number of capacitors charged in parallel and discharged in series, are used to simulate travelling-wave phenomena, the resistance-capacitance network of the output circuit being adjusted to give a unidirectional waveform with a steep wavefront rising to the crest value, and a slower rate of voltage decay on the tail. Such waves are defined by two time-intervals T_1 and T_2, in units of microseconds, where T_1 is the time to reach the crest value, and T_2 the time for the voltage to fall to half the crest value on the tail. A knowledge of the characteristics of those waveforms that would represent service conditions, and of those obtained in the laboratory, had to await the development of high speed, single-stroke oscillograph techniques [4]; then waves in which $T_1/T_2 = 1/5$ and $1/50$ were standardized for test purposes—although many other waveforms are necessarily used in research work.

When an impulse voltage is applied to an insulating medium, breakdown or spark-over may occur on the front, crest, or tail of the wave, according to the magnitude and shape of the wave and the characteristics of the insulation. For a given set of conditions, there is thus a time-to-breakdown, and the variation of this time with the magnitude of the voltage for each class of insulation in a transmission system is of great importance in the design of the equipment. The insulation of a system must be so co-ordinated that, in the event of a lightning disturbance, the protective gaps will flash over before dangerous voltages are reached on the equipment at the ends of the line. Thus, if the curves I–III of figure 1 represent the characteristics of the solid insulation, bushings, and protective rod gaps respectively, a high overvoltage rising within the time-interval A

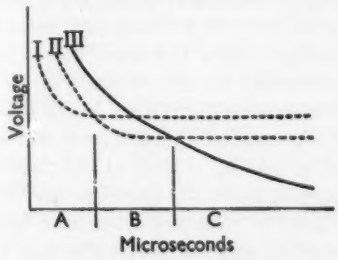


FIGURE 1 – *Voltage-time curves.*

would cause breakdown of the solid insulation; within the time B it would cause bushing flashover; and only when the voltage rose to a dangerous level at times within the region C would the rod gap afford the desired protection. It is necessary that the voltage-time characteristics for protective devices should lie wholly below those for the insulation of the system if complete protection is to be achieved.

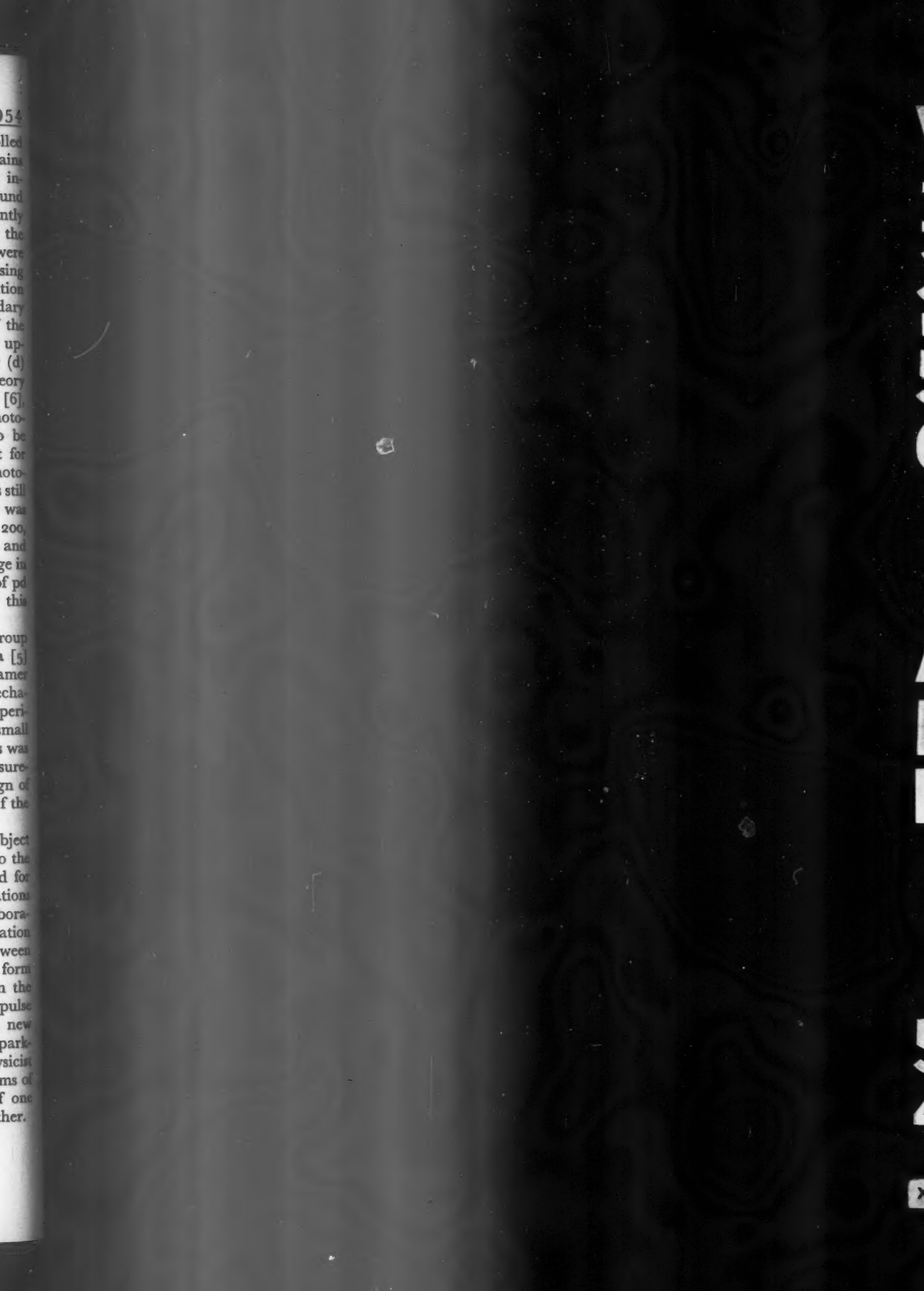
Electrical engineers have many problems of insulation for high alternating and impulse voltages that require a knowledge of how breakdown occurs through the air, as in the case of a protective gap. The wide variations that can occur in atmospheric conditions have to be considered, not only as affecting an air gap, but also with regard to their influence on the flashover of exposed insulator surfaces. In addition, a flashover due to lightning disturbances on an energized system can provide a path for power current, leading to the formation of an arc carrying the full short-circuit current of the system. Less obvious than conventional insulators, but of increasing importance as insulating media, are vacuum and high-pressure gas, and high D.C. voltages may become more widely used. There, too, an understanding of the mechanism of breakdown or spark-over is essential for satisfactory design of equipment.

VOLTAGE MEASUREMENT BY MEANS OF SPARK-GAPS

The measurement of high voltages in terms of the maximum length of spark that could be produced between two given electrodes in air was, for a time, the only method available—there was no theory or independent method of measurement to provide a check. The pioneer work of Townsend in formulating a physical theory for the mechanism of the spark initiated theoretical and experimental work that is continuing today [5]. Observations on the breakdown of atmospheric gaps under impulse-voltage conditions, and the development of high-speed oscillography and photographic recording, appeared to challenge the validity of the secondary ionization processes postulated by Townsend, as they were then understood. If the voltage across a gap is raised above the static sparking potential V_S to a value $(V_S + V)$ there is a measurable time-lag before breakdown occurs. This time-lag can be divided into two intervals, the statistical lag T_S, which is the time required for the appearance of an electron favourably placed to initiate primary ionization by an electron avalanche, and the formative lag T_F, which is the further time required for the breakdown mechanism to develop [6]. T_S can be controlled by suitable irradiation of the gap, but T_F remains as a characteristic of the physical processes involved in the breakdown mechanism. It was found that, provided the overvoltage V was sufficiently great, there was apparently no lower limit to the value of T_F, and values were obtained that were less than the transit times of positive ions crossing the gap to produce secondary ionization. Attention was thus focused on the nature of the secondary processes [6] involved, and measurements of the pre-breakdown current (I) did not reveal the up-curving of log I as a function of the spacing (d) required by Townsend's theory. A streamer theory of breakdown was accordingly advocated [6] based upon positive-ion space-charge and photo-ionization of the gas. This was claimed to be independent of the cathode and to account for very small values of T_F. But the theory of photo-ionization was qualitative only, and, what was still more significant, the Townsend mechanism was admitted for values of pd less than about 200, where p is the gas pressure in mm of mercury and d the gap spacing in cm. The apparent change in the mechanism at a critical value or range of pd indicated most clearly the need to explore this range experimentally.

Investigations carried out by the research group working with F. Llewellyn-Jones at Swansea [5] have revealed the deficiencies of the streamer theory, and have restored the Townsend mechanism to favour with both theoretical and experimental evidence, including explanation of small values of T_F. The success of the investigations was made possible by improved methods of measurement and stability, and by the correct design of the experiments [7], in which respect by itself the work is of very great interest.

If to the physicist the spark-gap was an object for study as a source of experimental data, to the engineer it remained as a specified standard for high-voltage measurement, and many calibrations for this purpose were made in engineering laboratories. This work also assisted in an appreciation of the practical problems of flash-over between electrodes of more complicated geometrical form than simple spheres. With each advance in the precision with which high alternating and impulse voltages could be controlled and measured, new data were obtained on the characteristics of spark-gaps [8], which had to be explained by the physicist and applied by the engineer to other problems of design; at the present time the interests of one can hardly be separated from those of the other.



As a voltmeter, the customary spark-gap consists of two equal spheres at a distance from one another not greater than their radius. At wider spacings the field becomes markedly non-uniform until, eventually, a corona discharge at the surface of the spheres precedes breakdown. In most cases, the gaps are used asymmetrically, the high voltage being applied to one sphere while the other is connected to earth. Variations were found in the calibration data obtained in different laboratories for these gaps. This was largely due to the asymmetry, and to the presence of earthed objects and of the building itself, which gave a higher gradient at the surface of the high-tension sphere [9]. Since the most favourable position for an electron to initiate an avalanche is in the vicinity of the cathode, the effect of asymmetry would be to give a lower breakdown voltage when the high voltage sphere was negative. Polarity indicators were therefore used to determine the polarity of the high-voltage sphere at the instant of breakdown with alternating voltages [10]. For spacings less than the radius of the spheres the field is not greatly affected by asymmetry, and flashover is independent of polarity. As the spacing is increased, the proportion of breakdowns during the negative half-cycle increases until it becomes 100 per cent. At still greater spacings the field between the spheres is more divergent, corona discharges can form at the surfaces owing to the high gradients there, and conditions close to the anode then determine events, so that breakdown occurs in the positive half-cycle [8]. Similar polarity characteristics would be expected when comparing calibration curves for positive and negative voltages, whether D.C. or impulse, and a correlation has been found between the A.C. and impulse calibrations [11].

The calibration and use of sphere gaps for high-voltage measurements were examined in detail; it became the practice to make a series of breakdown measurements at regular intervals and to plot a sequence diagram. It was not unusual to find, in a sequence, low freak values which could be explained as due to fortuitous circumstances such as the presence of dust particles, but high freak values were not observed. Surface effects were considered [12], and it was recommended that a number of conditioning breakdowns should precede those used for measurement, as even with a current-limiting resistance a film of tarnish forms on the surface of the sphere. As an aid to consistency, especially at small spacings, it was recommended that the gap should be irradiated from an external source.

Further difficulties were experienced in the use of sphere gaps for impulse voltage measurement. The effects of waveform were eliminated by making calibrations for specific limits to the wave-shape [12], but owing to the statistical spread of values of time-to-breakdown it was found that there was a range of voltage within which the frequency of breakdown varied from zero to 100 per cent for a number of successive applications of voltage. The breakdown voltage for a given gap was therefore defined as that voltage which produced spark-over on 50 per cent of the impulses.

THE UNIFORM-FIELD SPARK-GAP

Many difficulties inherent in the use of spherical electrodes for spark-gaps would be overcome if the path of the spark lay wholly within a region of uniform field strength. The fact that the field was uniform would dispose of the problems arising from asymmetry, and ion movement would not be influenced by longitudinal variations in the applied field. Such a field exists between infinite parallel planes, but for practical use the boundary effects have to be considered. In 1923, Rogowski [13] proposed an electrode contour conforming to an equipotential surface at the boundary of parallel planes, and such that the gradient on the curved edges was everywhere less than between the parallel surfaces. At that time, high alternating voltages could not be stabilized or measured very accurately, nor was there the empirical knowledge of spark phenomena that had accumulated some ten years later. In 1933, Stephenson [14] proposed a contour for uniform-field electrodes based upon studies of corona discharges, and preliminary observations indicated that this contour gave the desired characteristics; the spark-over voltage V could be defined by the equation

$$V = AS + B\sqrt{S},$$

where A and B are constants and S is the electrode separation. The writer and his colleagues subsequently undertook the calibration of these gaps for high alternating voltages [15]. The electrodes have a central plane area surrounded by curved edges, and must be mounted with the planes parallel to each other. At spacings up to a maximum, which is of the order of the diameter of the plane areas, sparking takes place in the region of uniform field; beyond this maximum the spark paths lie between the edges of the electrodes. These electrodes are made of a size appropriate to the maximum voltage that is to be measured. Three sizes were calibrated, and possible sources

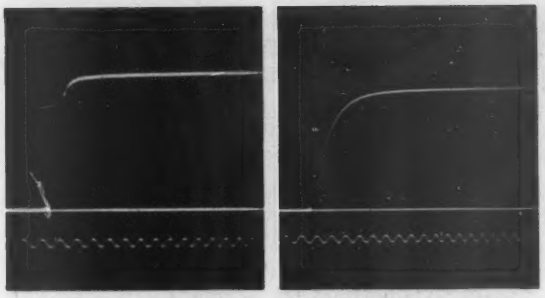


FIGURE 2 – 0·17 *and* 0·7 μsec *wavefronts.* 5 *Mc/s timing waves.*

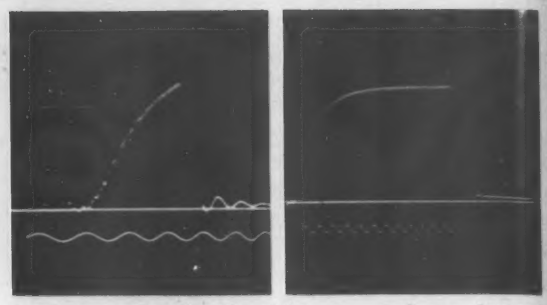
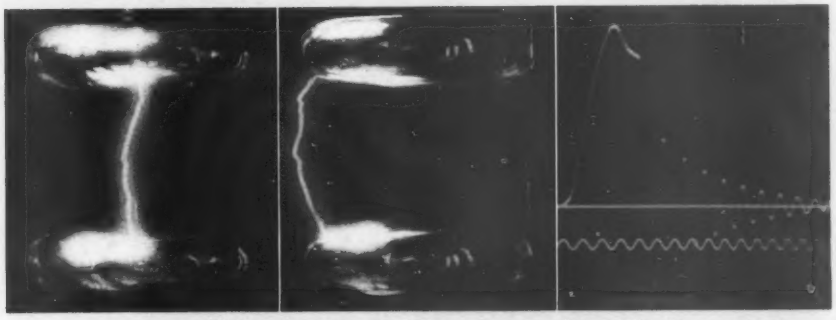


FIGURE 3 – *Records of breakdown on wavefront and wave-tail.* 5 *Mc/s timing waves.*



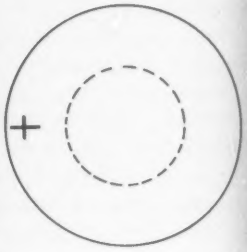


FIGURE 4 – *Main and suppressed discharges in non-uniform field.* 8·7 *cm spacing, upper electrode positive.*

In figures 4–10 the diagram shows the location of the spark roots.

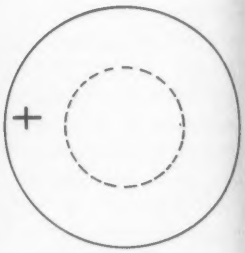


FIGURE 5 – *Non-uniform-field spark-over, showing bifurcation.* 8·7 *cm spacing. No filter. Upper electrode positive.*

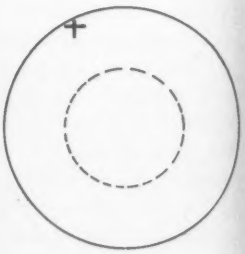


FIGURE 6 – *Non-uniform-field spark-over, showing stepped path.* 8·7 *cm spacing. No filter. Upper electrode positive.*

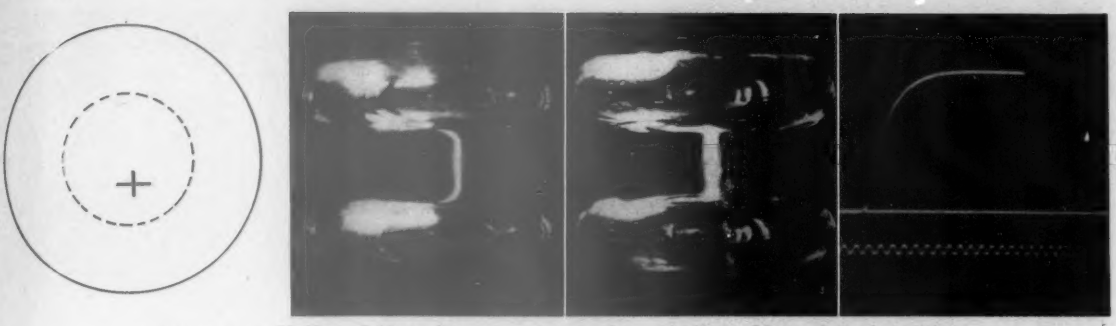


FIGURE 7 – *Uniform-field spark-over. 2·9 cm spacing. No filter. Upper electrode positive.*

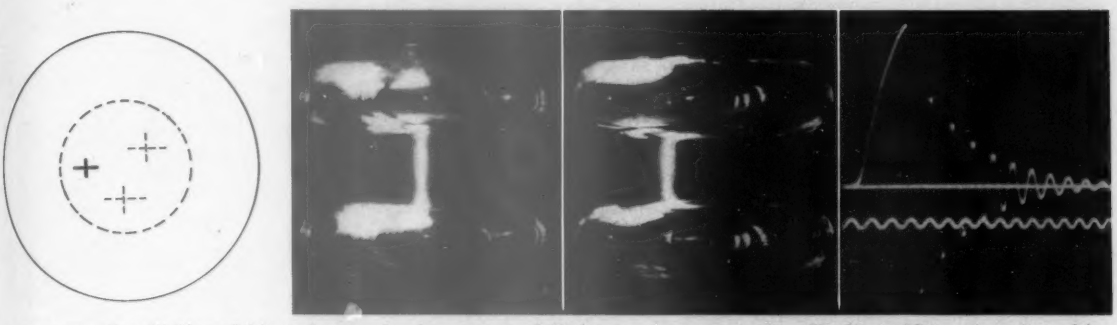


FIGURE 8 – *Uniform-field spark-over, showing suppressed discharges. 2·9 cm spacing. No filter. Upper electrode positive.*

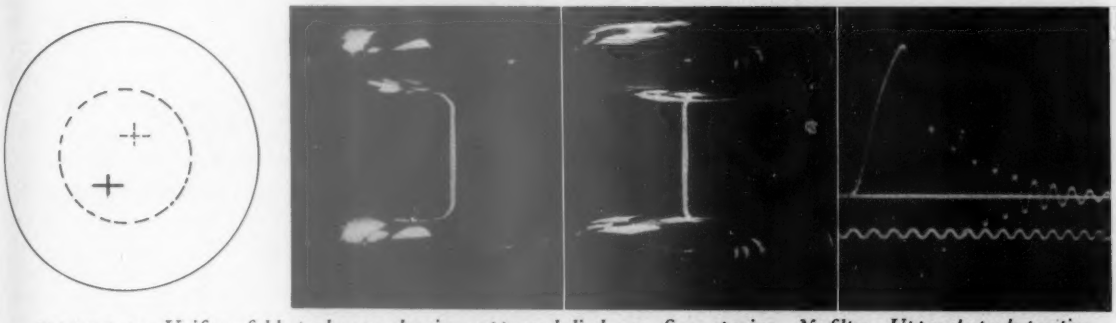


FIGURE 9 – *Uniform-field spark-over, showing suppressed discharge. 6 cm spacing. No filter. Upper electrode positive.*

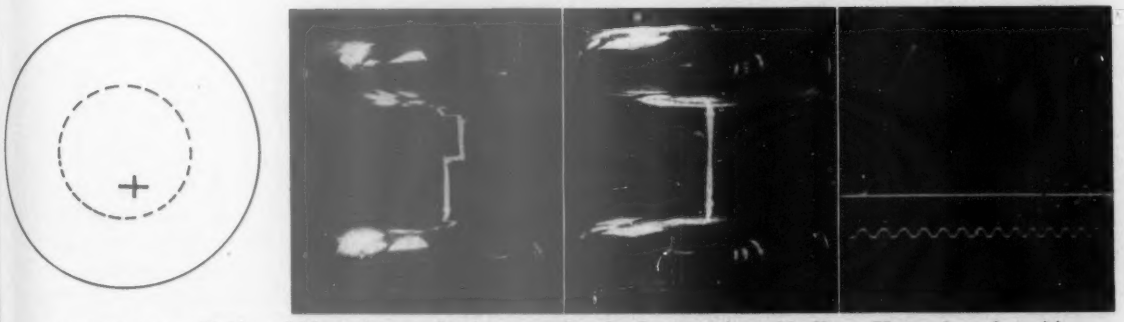
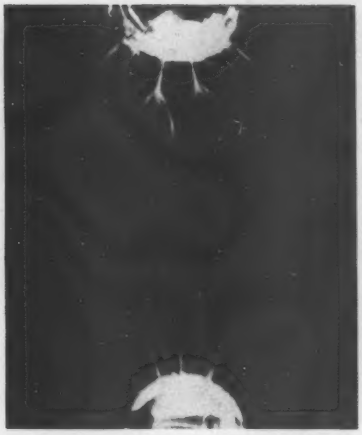


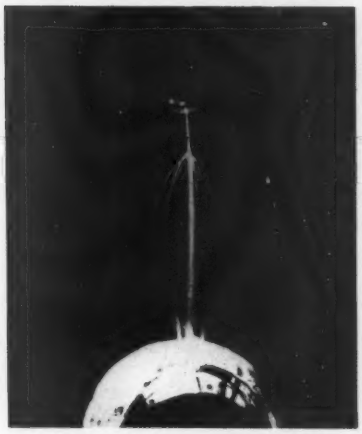
FIGURE 10 – *Uniform-field spark-over, showing stepped path. 6 cm spacing. No filter. Upper electrode positive.*

6·25 *cm spheres; 25 cm spacing.*

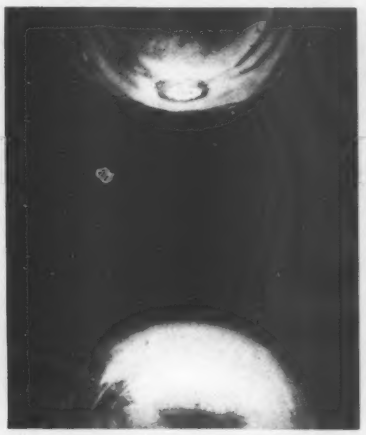


6·25 *cm spheres; 12·5 cm spacing.*

12·5 *cm spheres; 15 cm spacing.*



12·5 *cm spheres; 12·5 cm spacing.*



12·5 *cm spheres; 9·0 cm spacing.*

12·5 *cm spheres; 6·25 cm spacing.*

FIGURE 11 – *Suppressed discharges in air gaps. In all except the last two illustrations the upper sphere is positive.*

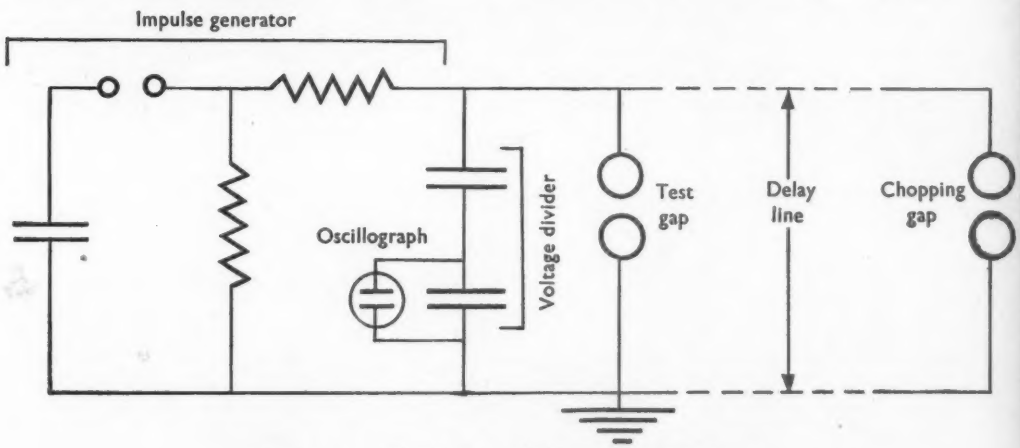


FIGURE 12 – *Circuit for producing suppressed discharges.*

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of error due to adjustment or proximity effects were investigated. Similar investigations were carried out with spheres of 25 cm diameter to provide a comparison and a link with other work on sphere gaps. In order to assess the significance of the small variations in breakdown voltage that were experienced in some of these tests, a considerable time was spent in developing and checking the accuracy of the peak voltmeter used as a reference, and the accuracy finally achieved was of the order of $\pm$ 0·03 per cent.

It was found that, for all sizes of electrode within their respective ranges of spacing, the spark-over voltage (in peak kV) was given by

$$V = 24{\cdot}22S + 6{\cdot}08_2\sqrt{S}$$

at 20° C and 760 mm Hg, where S was the spacing in cm. The departure of individual values from this equation was less than 0·2 per cent, and the average value of the mean deviations for the sequence diagrams was 0·06 per cent. The spark-over was independent of polarity, and the spark paths were uniformly distributed over the plane areas. This latter characteristic is a valuable indication that the flatness of the surfaces and the accuracy with which they are made parallel give sufficient uniformity of field. Since each spark path lies between different points on the electrode surfaces, there should not be any marked conditioning effect. This was confirmed by a series of polarity tests on newly cleaned electrodes and spheres, though low freak values that can be attributed to particles of dust may and do occur. Owing to the guard-ring action of the edges in screening the region of uniform field, proximity effects are much less than for the corresponding sphere gap, even at the maximum spacings.

The above results indicate that the uniform-field gap should be much more suitable than the sphere gap for impulse voltage measurement, and, for similar reasons, that it would be the better form of gap with which to study the mechanism of breakdowns. It does not exhibit a polarity effect, and the substantial volume of uniform field within which the spark can develop increases the probability that an electron will be favourably placed to initiate breakdown. This opinion was confirmed by some observations on the measurement of recurrent negative pulses [16].

With the provision of facilities for high-voltage investigations at the Royal Technical College, Glasgow, the writer was able to initiate a number of investigations on spark characteristics, making use of the special advantages offered by the uniform-field gaps for such work. The major points of interest were reported in 1951 [8], and subsequent progress is described below.

INVESTIGATIONS IN PROGRESS

A necessary preliminary to spark investigations is the provision of sources of stable voltage and independent methods of accurate voltage measurement. These have been developed during the last two years. For alternating voltages, an automatic controller of frequency and voltage was produced for the machines supplying the transformer [17]. All these features are important in obtaining good accuracy from the peak voltmeter, the performance of which is being investigated in considerable detail. The main problem in impulse voltage measurement lies in the voltage divider that must be used in conjunction with an oscillograph, and the problem is made more difficult when reliable measurements are required on very steep wavefronts. As in most other high-voltage laboratories, this matter has been under investigation at Glasgow in recent years, and continues to be so. A normal type of impulse plant is available for work with standard waveshapes, but waves with steep fronts and long tails are necessary for a study of spark mechanisms; for this work, impulse generators for voltages up to some hundreds of kV have been built. As much of the work is statistical, it is important that the generator output should, when desired, be constant on successive discharges, and this necessitates a stable charging voltage and accurate measurement of it. These remarks on equipment and techniques are mentioned to illustrate that the investigations now in progress aim at a higher order of accuracy than is usually obtained in such work. The development of suitable methods is not yet complete, but enough has been done to enable a preliminary survey of the scope of each investigation to be made, and to assess the suitability of the techniques developed.

EFFECT OF IRRADIATION ON IMPULSE BREAKDOWN

This work uses an impulse generator with a maximum output voltage of 100 kV, so that the dimensions of the gaps and supporting structures can be kept small enough for complete screening to be effected. The waveshapes used so far are 0·17/250 and 0·7/250, as shown in figure 2. Typical records of wavefront and wavetail breakdown are reproduced in figure 3. For sphere gaps, transition curves have been reported [18] from zero to 100 per cent breakdowns under various

conditions of irradiation, and the work is now being extended to uniform-field gaps, a variety of waveforms, and spark-over on the wavefronts. Simultaneous measurements are also being taken with spherical electrodes 6·25 cm in diameter.

In the condition described as non-irradiated, the gap is completely shielded by a pressboard box of adequate dimensions. Light from the generator gaps is used for ultraviolet irradiation, and the equivalent of 0·5 mg of radium is inserted below the surface of one electrode for radium irradiation. The relative effects of these conditions have been determined by the transition curves shown in figures 13–16, the gap spacing being about 2 cm in all cases. The voltage range ΔV for a transition from zero to 100 per cent breakdown is plotted as a percentage of the voltage for zero breakdown. With non-irradiated gaps (figures 13 and 14), ΔV for the uniform-field gap is much less than for the sphere gap, and is not greatly affected by polarity or wavefront changes. With irradiation, the curves are drawn for 0·17 and 0·7 microsecond wavefronts (figures 15 and 16) respectively. In the case of the uniform-field gap, one curve could serve for all combinations of irradiation, polarity, and wavefront, but for the sphere gap the ultraviolet irradiation has been less effective than radium in reducing ΔV, especially with the longer wavefront. The results from all four figures confirm the advantages that were expected from using uniform-field gaps under these conditions. For practical purposes the spark-over voltage is defined as that giving 50 per cent breakdowns, and as a means of comparing the different characteristics it is suggested that the slope of the curve at 50 per cent breakdown could be regarded as a figure of merit. This has been expressed as the value of ΔV per cent for 0–100 per cent transition as given by the tangent to the curves at 50 per cent. The results are given in the accompanying table.

From oscillograms taken during the above tests and with overvoltages, the

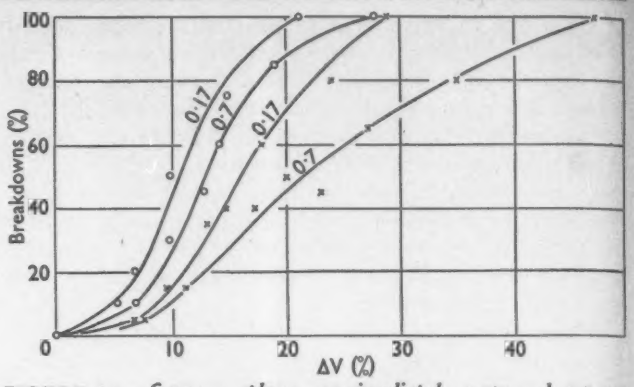

FIGURE 13 – 6·25 *cm spheres, non-irradiated,* 0·17 *and* 0·7 *μsec wavefronts.* o = *positive waves;* x = *negative waves.*

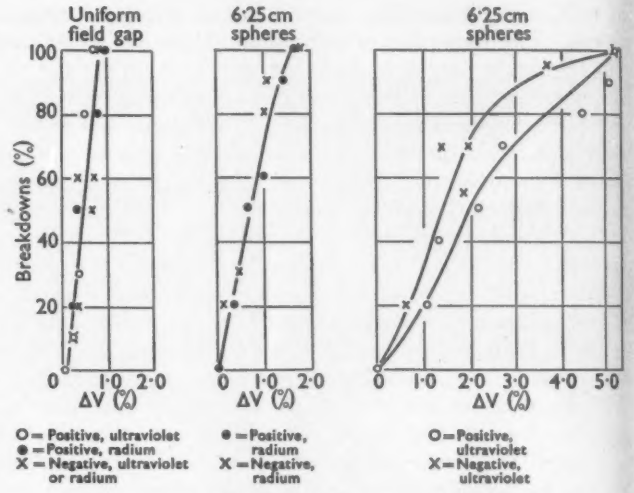

FIGURE 16 – *Curves for* 0·7 *μsec wavefront.*

TABLE

Figure of merit for the particular spark-gaps investigated

Irradiation	6·25 *cm spheres*				140 *kV uniform-field electrodes*			
	Positive		*Negative*		*Positive*		*Negative*	
	Wavefront				*Wavefront*			
	0·17	0·7	0·17	0·7	0·17	0·7	0·17	0·7
None	21·0	27·0	28·0	46·0	8·8	9·8	11·0	13·0
Ultraviolet ..	2·8	5·2	2·8	5·2	0·8	0·7	0·6	0·8
Radium ..	1·6	1·6	1·5	1·7	0·8	0·9	0·8	0·8

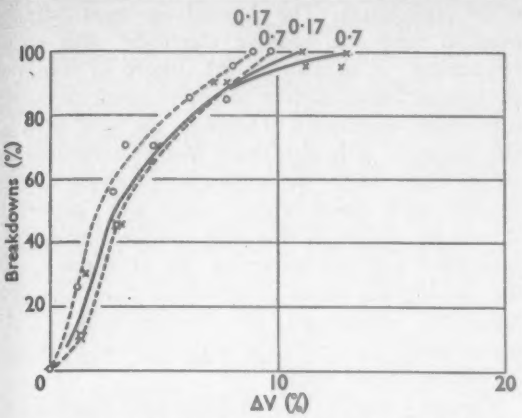

FIGURE 14 – *Uniform-field gap, non-irradiated.* o = *positive waves;* x = *negative waves.*

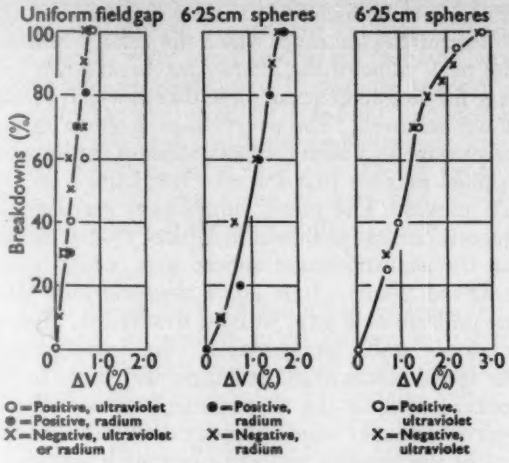

FIGURE 15 – *Curves for* 0·17 μsec *wavefront.*

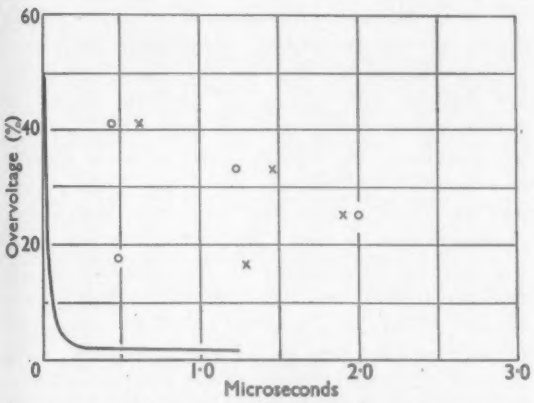

FIGURE 17 – 6·25 *cm spheres, time-lag for* 0·17 μsec *wavefront. Curve = irradiated gap,* ± *waves;* o, x = *non-irradiated gap,* ± *waves.*

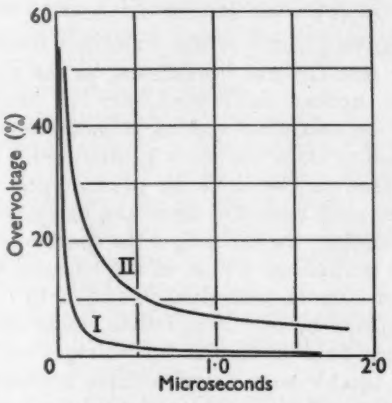

FIGURE 18 – *Uniform-field gap, time-lags for* 0·17 μsec *wavefront. I = Radium or ultraviolet irradiation,* ± *waves; II = non-irradiated.*

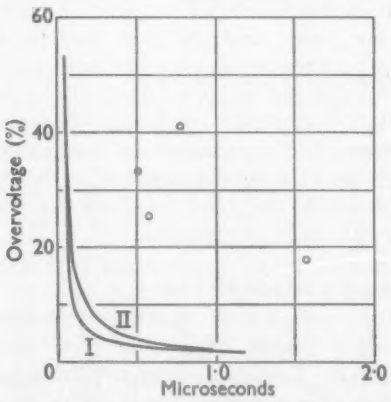

FIGURE 9 – 6·25 *cm spheres, time-lags for* 0·7 μsec *wavefront. I = Radium,* ± *waves; II = ultraviolet,* ± *waves;* o = *non-irradiated, positive.*

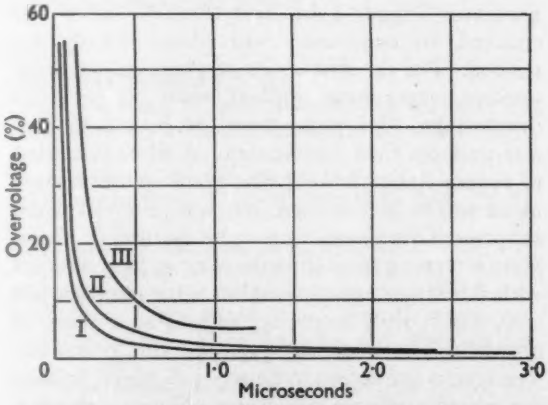

FIGURE 20 – *Uniform-field gap, time-lags for* 0·7 μsec *wavefront. I = ultraviolet,* ± *waves; II = radium,* ± *waves; III = non-irradiated,* ± *waves.*

time-lag to breakdown has been measured as the time from the instant at which the voltage reached the peak value of the alternating breakdown voltage for the gap in question, to that at which breakdown occurred. The overvoltage is given as the percentage by which the peak value of the impulse applied exceeds that for zero breakdown on the ΔV curves. The mean values gave surprisingly smooth curves, as shown in figures 17–20, except for the non-irradiated sphere gap, which gives scattered points. It is again demonstrated that the uniform-field gap, without irradiation, gives a relatively stable performance. For investigating the spark mechanism, attention will have to be concentrated on the characteristic at very small overvoltages, for which purpose the accurate control of the impulse generator output is essential; D.C. voltages may be used also.

PHOTOGRAPHY OF SPARK CHANNELS

For investigations of the transition from uniform to non-uniform breakdown, as the spacing between uniform-field electrodes is increased beyond the maximum spacing of their range, it is important to know the exact location of the spark path. This can be done by photographs taken simultaneously from two directions perpendicular to one another; the location of the spark roots can then be plotted on a plan of the electrodes. By means of mirrors, such dual photographs can be obtained side by side using only a single camera.

Uniform-field electrodes for voltages up to a peak of 140 kV were found to have a maximum spacing for uniform-field breakdown lying between the values of 6·2 and 7·2 cm [15]. These electrodes were set up for uniform-field breakdown when irradiated by light from the impulse-generator trigger gaps, and the ΔV curve was checked for conformity with those already described. For the first series of photographs, 1/50 positive waves were applied, with 50 per cent overvoltage, to a gap spaced at 8·7 cm to give non-uniform field breakdown. A filter was used to reduce halation when the main spark-channel alone was to be recorded, but was removed when suppressed discharges were to be examined. Complete screening from the generator gaps is difficult with this larger equipment, but some photographs were taken with screening limited to a sheet of pressboard between the gap and the generator. The results are shown in figures 4–6, together with the corresponding oscillograms. Figure 4 shows a large number of discharges occurring in the non-uniform field and suppressed by the development of the main spark. The channels are most strongly marked near the positive electrode, and show branching. A similar record (figure 5) shows a prominent bifurcation in the main spark channel; suppressed discharges, if present, are very faint in this instance, although there was no screening in either case. With the screen in position, a discharge with pronounced steps was recorded (figure 6), although this may not be specifically associated with the screening. In all three cases, the oscillogram shows pronounced distortion just before the breakdown; this phenomenon will be investigated in conjunction with records of the gap current in future work.

Figures 7 and 8 show uniform-field breakdown for a spacing of 2·9 cm, with the screen in position. Breakdown on the tail in figure 7 shows an almost straight path, the apparent curvature at the ends resulting from reflection in the electrode surfaces. When an overvoltage is applied to obtain breakdown on the wavefront, suppressed discharges appear (figure 8), but all the discharge paths are straight and within the uniform field. At a spacing of 6 cm, uniform-field breakdown is still obtained, and figures 9 and 10 show records of wavefront breakdown. In figure 9 the screen was in position, and one prominent suppressed discharge can be seen. An interesting feature is the increase in intensity of this channel in the mid-gap region, which is revealed in both views. Figure 10 was taken with the screen removed, and shows a striking step in the spark channel. This was not a unique example of a step in the uniform-field breakdown, and the matter will be investigated further. Up to the present, these steps have been found when the screen was removed. Since the field is uniform, there is no reason why the electron avalanches should originate from any one particular plane, and the step may be due to bridging between two avalanche tracks, one beginning from mid-gap and one from near the cathode.

The fact that, under conditions of overvoltage, the uniform-field gap can have a number of spark channels developing simultaneously, is again a confirmation of the short time-lags and the consistency that may be expected.

SUPPRESSED DISCHARGES

Another programme mentioned earlier [8], from which results have now been obtained, derives from Torok's technique of suppressing discharges after a certain time, either by reflections in a short-circuiting loop connected across the gap, or by chopping with a second gap in

parallel [19]. In the present work it was decided to combine the two techniques to find if an easier control could thus be gained, and present indications are that this has been achieved. The circuit used is shown in figure 12. A selection from the first series of photographs taken in the preliminary work is reproduced in figure 11, and, reading from left to right along the two lines, the photographs show an approach in successive stages to a uniform field using spherical electrodes. For the last two records, the polarity of the impulses applied to the upper sphere was changed to negative, and a comparison with the previous photographs shows that the structure of the discharge is determined by polarity and not by asymmetry. In all cases, high overvoltages of about 600 kV were applied, with the chopping gap set to flash over at 300 kV, falling to 200 kV as the spacings were reduced. Similar records have not yet been obtained for a uniform-field gap.

There is great similarity between the discharge structures at the positive and negative electrodes and Lichtenberg figures of corresponding polarity, and probably the two phenomena are to be explained on similar lines. In the vicinity of the cathode, electron avalanches diverge into a region of lower field strength. At the anode, in the region of maximum field strength, electrons are swept in from the air, leaving a positive space-charge to which electrons arriving from mid-gap will be attracted and so drawn into the same channel. The second and third photographs suggest that the branching occurs at a distance from the surface of the anode which varies with the surface gradient at that point. The fourth photograph shows a single channel across a gap-spacing that is approved for impulse voltage measurement [12], but, like the others, it is diffuse towards the cathode. All the gaps shown were irradiated to an indeterminate extent by the trigger gaps of the impulse generator.

Contemporary work by Norinder and Salka, and by Pucher [20], with sphere-plane gaps, gives similar results in the vicinity of a positive sphere; with a quartz lens, these workers find a very strong intensity at the ends of the channel.

CONCLUSION

From the above work and allied investigations, it will soon be possible to give a second calibration of the uniform-field gap for high alternating voltages, and a calibration for impulse voltages under specified conditions. These calibrations provide a datum from which variations can be judged, and the whole should make a useful contribution to spark theory. Other investigations will show how the Townsend mechanism functions in highly divergent fields, for the suppressed-discharge technique will be extended to the case of a positive point discharge.

In the limiting case of long sparks, the lightning discharge, it is known that the leader stroke advances in a series of current pulses or steps which successively increase in length. One theory to account for this [21] is based on a glow-to-arc discharge transition; it may be possible by the suppressed discharge technique to find evidence concerning this question, if an arc column is found to exist at the anode of a divergent field before breakdown is complete.

ACKNOWLEDGMENTS

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The Bermuda Islands

T. A. and ANNE STEPHENSON

The Bermuda Islands, separated by nearly 600 miles of ocean from the nearest land, and surrounded by warm water in the fringe of the Sargasso Sea and within reach of the Gulf Stream, offer great attractions to biologists who wish to study the fauna and flora of oceanic islands. Professor Stephenson and his wife have recently made such a study, and here describe some of their observations. The rocky reefs around Bermuda present features of much interest.

The Bermuda archipelago (figure 1), while including many individual islands, is very compact. Most of the islands are small; only five of them are of any considerable size, and these are linked by bridges. The larger ones consist of low hills, and much of the coastline is steep or precipitous. Because of the oceanic position, the most exposed coasts of the islands, and the surrounding reefs, are subject to very powerful wave-action from the enormous Atlantic swells; this is so persistent that in the most wave-washed places there is only a limited number of days in the year when it is possible to land and work on them. The islands are situated on the top of a submarine mountain and are surrounded, below the water, by sand-covered banks from which arise hundreds of rocky reefs. These reefs not only have a definite arrangement in relation to the islands, but show peculiarities of structure which place them among the most interesting products of combined organic and inorganic activity to be found in the world.

The islands have a considerable human population, varying in colour from black to white, and a flourishing tourist trade, especially from America. There are two towns, Hamilton and St George's. Near the latter is situated the Bermuda Biological Station, where, with the assistance of the Royal Society and the American Philosophical Society, we were able to spend three months in the summer of 1952. The land-vegetation of the islands is of a typically subtropical nature. Bananas are grown, and hibiscus (figure 14), oleander, frangipani, bougainvillea, and various other flowering trees flourish. Many of these have been imported for garden purposes.

A recent development of plant and animal geography has been an attempt to correlate the distribution of water-masses of different temperatures over the face of the Earth with the distribution of populations of plants and animals. The dependence of marine organisms upon a certain temperature-range for their very life, and their great sensitivity to it in their distribution, have been emphasized in many different ways. One of the striking examples was provided by Bermuda itself in 1901, when a spell of unusually cold weather early in the year resulted in the death from cold (but at temperatures well above zero) of large quantities of the warm-water fish which live around the islands, as well as of corals and other invertebrates. The Bermudian waters can by no means be classified as tropical, and although the term subtropical may suitably be applied to them, they have the peculiarity that in the summers they are almost as warm as those in some marginal tropical areas, such as the Florida Keys. On the other hand, in the winters they are decidedly cooler than those in any tropical region, and even cooler than those in some other subtropical ones. Consequently, many warm-water species which inhabit the Bermudian seas are living, in winter, at temperatures fairly close to the lower limit which they can tolerate, so that a cold spell such as that of 1901 can cause extensive devastation. An interesting question is whether the annual cycle of temperature at the Bermudas is warm enough to permit the growth of coral-reefs, and with this we shall now deal.

Rocky reefs arising from the sea-floor can be of several types. Many of them are merely outcrops of whatever rock is characteristic of the region in which they are found. Others are built up entirely of the skeletons of living plants and animals; the largest and most impressive of these are found only in shallow tropical seas and are known as coral-reefs. These reefs do not necessarily contain any material whatever of geological origin; the whole rock of which they consist is derived from the skeletons of organisms, primarily corals and calcareous algae. The reefs about Bermuda are particularly interesting because they seem to be intermediate between the two types just described.

While they are of every imaginable shape, they belong roughly to two varieties. In one form the reef is wholly submerged, so that the top of it never emerges from the sea and is not even awash at the lowest tides, though often very near the surface. These reefs are irregular in shape and very variable in size and in the height to which they rise above the surrounding sea-floor, but they are often very sharply delimited and commonly have precipitous and overhanging sides. Over their surfaces grow corals in moderate numbers, and groves of those supple and perpetually waving alcyonarians known as gorgonians. The prevailing colours are brown, purple, and yellow, with every possible shade and gradation of these tints; the effect is very beautiful. In the waters swim tropical fish in profusion, of every shape and colour. In some places there is a direct transition from the coastal rocks to reefs of this type. The reefs of the second variety, which are locally called boilers, are most peculiar structures. Their highest parts reach the surface of the sea and are awash or project a little above sea-level at low tide, but in ordinary weather the surf boils over and around many of them so heavily that it is impossible to keep a footing on them. By choosing one's day, however, it is feasible to explore them, though even then the emergent tops are often sufficiently washed to be permanently wet. Many of them have the shape of a funnel with a thick stem (figure 11). From the stem the reef expands to its overhanging margin, which

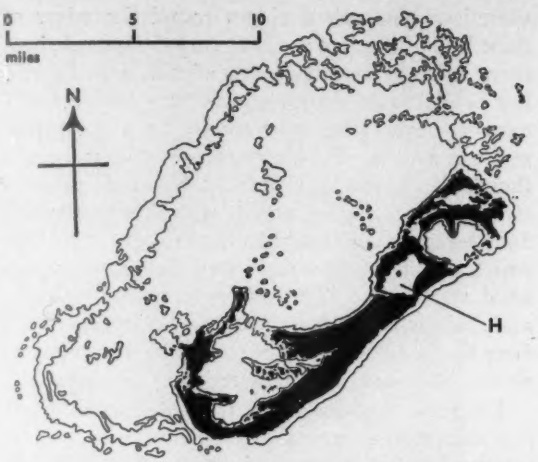

FIGURE 1 – *The Bermuda Islands. Land is shown in black, and the main sand-banks from which the reefs arise are indicated in outline.* H, *Harrington Sound.*

forms a raised rim round its edge. Inside is a hollow, sometimes descending right down through the centre of the funnel to the level of the sandy floor surrounding the boiler. The sides of the latter are often perforated by holes or clefts, so that water can enter the funnel from below and rise up inside it. While in the simplest cases the shape is that of a neat funnel or mushroom, in many others it becomes complicated and irregular, so that it may present a cluster of irregular funnels, a long narrow ribbon-like form (figure 2), and other

FIGURE 2 – *Diagram showing the general appearance of an elongated 'boiler,' with an indication of the shape of the parts lying below the surface of the sea. Inset: Section of a similar boiler.*

varieties. The raised ridges round the edges of these boilers (figures 2–4) are very characteristic of them and are formed neither of rock nor of coral, but primarily of masses of narrow worm-like calcareous tubes belonging chiefly to a gastropod mollusc known as *Spiroglyphus irregularis*. Over these tubes grows a profusion of short seaweeds—especially brown ones, among which *Sargassum* and *Dilophus* are particularly common—and it is these which give the ridges their very distinctive superficial appearance. The boilers often enclose deep and shallow pools; these pools and submerged surfaces frequently support corals and gorgonians, as well as many and varied seaweeds and invertebrates.

The rock of which the Bermuda Islands consist is a material known as aeolian limestone, which weathers along the shores into all manner of fantastic shapes and is much pitted and honeycombed by rain, sea, and wind. It was formed originally from dunes built up by wind-blown calcareous sand. The interesting feature is that the boilers just described appear to have their foundations made of this aeolian limestone, carved into peculiar shapes by the sea, but built up and veneered (and so protected from further attack by the sea) by *Spiroglyphus* and its associates near the surface and by other organisms lower down. They are not coral-reefs, but rather rocky reefs changed by wave-action and supplemented by organisms. There seems, further, to be little doubt that even the submerged reefs first described are not coral-reefs either, despite their growth of coral and gorgonians, but are bastard structures of aeolian limestone built up to a limited extent by corals and other organisms. The water in which they live is not warm enough in winter to support anything approaching a full growth of reef-building corals. Those found at Bermuda belong to a small selection of species as compared with the tropical Pacific; they are not comparable in size or profusion with those found on Pacific reefs; and they do not show a comparable range of colour and form. They are primarily brown to yellow in colour and massive in form, and the stagshorn shapes so plentiful in warmer waters are represented in Bermuda only by *Millepora*. The leading reef-building stagshorn genus *Acropora* is apparently absent altogether. One of the most spectacular and beautiful features of the Bermudian reefs—the lilac, purple, fawn, and brown sea-fans and other gorgonians—is a feature not of Bermuda in particular, but of Atlantic warm-water reefs as distinct from Pacific ones.

In describing the boilers, mention has been made of the calcareous tubes of *Spiroglyphus*. This animal belongs to the gastropod family Vermetidae, whose members are not like snails or slugs but worm-like; they secrete calcareous tubes which attach them permanently to the rock. In some vermetids the individual tubes are small, but occur gregariously in such millions that they build up in time substantial amounts of what has sometimes been called worm-rock. This family Vermetidae is in itself a most interesting subject for biological research, and has not hitherto received the attention it deserves. For instance, its species, whose tubes look very like those of polychaet worms and are quite irregular, are by no means easy to classify or identify; at present we do not know how many species exist or exactly what are their limits or their distributions. To make a satisfactory identification of a vermetid, one must have the animal's operculum (which closes the mouth of the tube when it contracts) and specimens of the shell of newly born young, as well as of adults, not to mention the soft parts. In the past, many collections have consisted of the tubes alone, which are of little value. Fortunately the family is at present being revised along new lines by Myra Keen of Stanford University, who notes that in all our samples *Spiroglyphus irregularis* formed the bulk of the material, that a second species (*Petaloconchus nigricans*) was present in some of them, and that there were also true worm (polychaet) tubes in small amounts. She also notes that a third vermetid (*Spiroglyphus corrodens*), which had been supposed to be distinct from *S. irregularis*, is conclusively proved by this collection to be merely the form into which *S. irregularis* grows if not crowded; and that *Petaloconchus nigricans*, a Floridian species, had not previously been recorded from Bermuda.

The position of Bermuda on the fringe of the Sargasso Sea gives it an interest in another direction. As is well known, the Sargasso Sea is an immense eddy-like area of the Atlantic in which there float larger and smaller masses of brown seaweed known as Sargasso weed, belonging mainly to two pelagic species of *Sargassum* which are usually infertile. The origin of this weed is one of the mysteries of biology. A good deal has been written about it, and the central question concerning it is: was all this floating weed originally torn up from sea-floors in the West Indian region where *Sargassum* grows, or is it a self-perpetuating growth which has not been derived from any source now existing on the Earth, having originated from attached weed-beds in the remote past? One of the puzzles connected with it is the fact that the Sargasso weed is not specifically identical with any

FIGURE 3 – *Pinnacle of aeolian limestone, surrounded by fringing reefs veneered by the vermetid gastropod* Spiroglyphus irregularis.

FIGURE 4 – *Fringing reef seen from the top of a limestone pinnacle, showing ridges of* Spiroglyphus *overgrown by short algae.*

FIGURE 5 – *The coast of Gibbet Island, showing zonation between tide marks.*

FIGURE 6 – *The outer coast of Bermuda: vegetation and aeolian limestone.*

FIGURE 7 – *Harrington Sound, an enclosed marine area with an unusually narrow intertidal zone.*

FIGURE 8 – *Harrington Sound: healthy submerged growth of attached* Sargassum.

FIGURE 7 – *Harrington Sound, an enclosed marine area with an unusually narrow intertidal zone.*

FIGURE 8 – *Harrington Sound: healthy submerged growth of attached* Sargassum.

FIGURE 9 – *General view of boiler reefs, forming one irregular line near the coast and another farther offshore.*

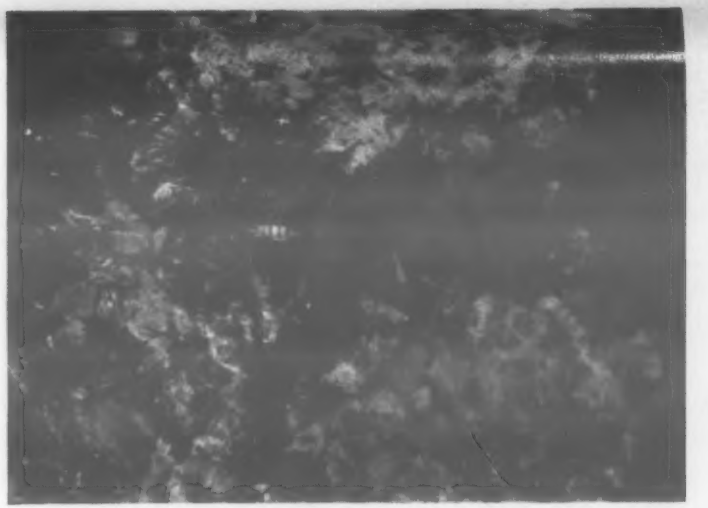

FIGURE 10 – *Submerged corals and gorgonians, with fish, on an offshore reef.*

FIGURE 11 – *Funnel-shaped boiler close to the coast.*

FIGURE 12 – *Flat-topped boiler with central cavity.*

FIGURE 13 – *Typical Bermuda scenery, near St George's. Oleander in right foreground; branches of native Bermuda juniper intruding at right and left.*

FIGURE 14 – *Part of a* Hibiscus *hedge near St George's.*

Photographs by Anne Stephenson

1951

form of *Sargassum* at present known in an attached condition. This difficulty is not insuperable, because it is known from experimental evidence that the growth-form of similar brown weeds (*Fucus*) can be changed if they are grown tangled up in wire netting instead of attached to the sea-floor, and that the Fucales in general tend to become modified if they grow unattached. Yet the pelagic *Sargassum* has not been produced experimentally from any attached species, so far as we know. Among the published discussions of the subject there is a particularly ingenious one by Parr [1], who surveys the known beds of *Sargassum* from which the floating weed could have been derived, and concludes that their bulk is altogether too small to have supplied the vast amount of weed in the Sargasso Sea, except on the assumption that it can be maintained by quite a small annual contribution and that it lives and grows for a very long time. In this connection we should like to draw attention to a point concerning the Bermudas. In any voyage round these islands one is likely to see floating *Sargassum*. Is there any source in Bermuda from which some of it could be derived? Here we think that, although it has long been known to botanists that species of *Sargassum* occur attached at Bermuda, it has perhaps not been realized how abundant they really are. From a little above the level of low water downwards, the growth of at least two species of this genus is extremely profuse all round Bermuda and in Harrington Sound. Many of the plants near low-water level are very short (a few inches long), but they are plentiful; and, below the water, healthy groves of plants a foot or more long are common (figure 8). It is true that these plants are quite different from the floating ones, but if the Sargasso weed is derived from any existing source, this applies wherever the source may be. It may also be true that if the total bulk of *Sargassum* round Bermuda could be weighed, it would not be great enough to count as one of the adequate sources of the floating weed. But whatever the bulk may be, it is substantial; and as the islands are subject to very powerful wave-action as well as to occasional hurricanes, much *Sargassum* must undoubtedly be torn away from the rocks, and it cannot but form a significant source of floating weed, considering how long this process has been going on—if it is capable of survival and transformation after it has become detached.

The Bermudas are no exception to the general rule that rocks between tidemarks are populated by plants and animals which are arranged in belts or zones one above another. It is now becoming generally realized that zones of this type show some common features all over the world, as well as many local differences, but we have not as yet had a detailed description of the zonation on isolated oceanic islands in relation to these universal features. This description can now be supplied, and it is interesting to find that the Bermudas fit in very well with the general plan. On the typical open coasts the following series is to be seen (figure 5). Just above the level of low water of spring tides is the margin (infralittoral fringe) of the rich growth of seaweeds which carpets the rocks from low-water level downwards. Here there are short plants of *Sargassum* with a variety of other short algae, often ending in a strip of the brown fan-like weed *Padina*. Above this level the growth of algae is all very small (except where strong wave-action carries some of the larger species higher up), and consists rather of a short pile or moss-like growth, often intermittent, than of larger plants. The middle part of the shore (midlittoral zone) shows upper and lower subdivisions. In the lower, the rock is veneered by *Spiroglyphus*, accompanied by a sparse brown pile of small algae, among which *Gelidium pusillum* v. *conchicola* seems to be important. The limpet *Fissurella barbadensis* is one of the characteristic animals. In the upper subzone are often numerous barnacles (*Chthamalus stellatus*), frequently accompanied by patches of moss-like fur consisting of short algae, among which *Polysiphonia howei* is particularly common. The proportion of barnacles to algal fur in this belt varies according to the amount of sun and wave-action experienced by any particular area of rock, and depends also on the angle of the slope. Above the midlittoral is the supralittoral fringe, near high-water level, where the rock shows one of the most typical of the universal features of the zonation, a belt in which its surface is blackened by microscopic Myxophyceae (black zone). At this level, which is often very dry, macroscopic algae are limited to specially adapted forms (particularly *Bostrychia tenella*) living in hollows, and the commonest animals are rapid isopods (*Ligia baudiniana*). The details just given apply to typical open slopes; in situations of other kinds all manner of variations may appear.

There is a very pretty problem awaiting solution in Bermuda; it is linked with the development of the zones just described, and is of geological as well as biological interest. The aeolian rock of the Bermudian shores, at the higher shore levels, has a very characteristic sculpture. It is commonly excessively pitted and honeycombed, with sharp edges, points, and angles. In the tidal belt it becomes

progressively smoothed off, until in the lower part of this belt it has quite reasonably smooth contours, covered by the *Spiroglyphus* and the pile of short algae already described. This differential smoothing is no doubt due partly, but not entirely, to incessant wave-action, and to a cementing effect of the sea-water on the rock surface. It is evidently due also, in part, to the small-scale scraping action, over the rock surface, of the thousands of animals that feed on the films and furs of small algae growing upon it. Among these animals can be included chitons, certain snails and crabs, limpets, and fishes with hard beaks, such as parrot-fish. The surface of the rock bears innumerable markings showing where these creatures have been feeding. It would be a fascinating study to determine which animals make which marks, and to discover what share each of them has in the general process of smoothing. It is certain that they can affect the zonation. We were surprised to find, for instance, that on some of the rocks the black zone mentioned above was not developed where one would expect it. Close examination showed that the Myxophyceae which blacken the rock had in fact developed at the usual levels but had been so extensively consumed by animals that the surviving residue was not enough to form the general blackening which causes a black zone, with the result that the rock was unusually pallid and barren.

One of the objects of our expedition was to compare the Bermudas with the Florida Keys. It has long been recognized that the marine population of the Bermudas is related to that of the West Indies, and it has been assumed that many Bermudian species reached the islands from the West Indies, carried by Gulf Stream water, in the form of larvae or of individuals attached to floating objects such as seaweed and logs, or by other means. We have nothing to urge against this conclusion, which is in fact strengthened by our own work, but were concerned rather to discover whether the zonation and general distribution of the species resembled that of the Keys. The islands of this 100-mile chain are subject to exceptional circumstances, including unusually shallow seas adjacent to their coasts, a peculiarly heavy fall of sediment, and reduced exposure to wave-action. Within this framework they support a tropical population, modified by the disabilities of the surroundings. In Bermuda, on the other hand, the open coast is subject to none of these features, but there exist among the islands sheltered areas of enclosed sea which form an environment comparable to that of the Keys. In some of these we were interested to find a population and zonation very reminiscent of that characteristic of the Keys, and showing features not present on the outer, more wave-swept coasts. The zonation on the latter, while differing significantly from that of the Keys, may be understood as a rough-water modification of it. It was further interesting to find that many of the ecologically important species, that is the common ones characteristic of particular habitats, were the same in Bermuda as on the Keys. There are, of course, differences as well, and these can be used to demonstrate the contrast between the truly tropical marine climate of the Keys and the subtropical but oceanic climate of Bermuda. It appears also that the isolation of the latter has produced its own effect. The commonest shore barnacle of the Keys, for instance, is *Chthamalus stellatus*, subspecies *angustitergum*. The barnacle at present commonest in Bermuda, while again a subspecies of *Chthamalus stellatus*, differs both from the *angustitergum* form of that animal and also from *Chthamalus fragilis* (another North American barnacle), so that it is in fact a form new to science and will be described as a new subspecies by Dora Henry of Seattle, who examined our collection. This suggests that it has changed in Bermuda since it first reached the islands.

Finally it may be noted that an expedition such as this, although aiming primarily at something else, often produces incidental results which are interesting in themselves. Our boatman drew our attention one day to some very peculiar bright green barnacles growing plentifully under an overhanging cliff on an isolated offshore island. We saw at once that they were unusual, and collected some; we found them nowhere else during our three months' work. It became clear on returning to the laboratory that they belonged to a most peculiar species in which the shell, instead of consisting of 4–8 plates as in most common shore barnacles, is made up of a large number of overlapping ones. The animal is called *Catophragmus imbricatus*, and had been known previously only from a very few immature or incomplete specimens, described by Darwin in 1854 and by Verrill in 1901. It will now be possible for Dora Henry to describe the species, for the first time, from a reasonable number of well grown individuals.

REFERENCE

[1] PARR, A. E. *Bull. Bingham oceanogr. Coll.*, 6, 1939.

The nature of the upper atmosphere

H. S. W. MASSEY

One difficulty successfully overcome by the Everest expedition of 1953 was the thinness of the atmosphere at the heights scaled, and it might be natural to assume that at much greater levels there is so little air that no effects of any importance arise from its existence. Nothing could, in fact, be further from the truth, and some of the most important effects of the atmosphere which make life possible on the Earth's surface are located at very high levels.

Three vital functions are performed by the atmosphere—thermal insulation, removal of lethal ultra-violet light from solar radiation, and the volatilization of meteors. The ultra-violet absorption takes place mainly at an altitude between 20 and 40 km, where there is a concentration of ozone. The volatilization of meteors, on the other hand, takes place at about 100 km. The thermal effects of the atmosphere depend on its properties over a wide range of altitude. This is because a number of processes are involved—absorption of the short-wave solar radiation, which takes place at great heights, its degradation to long wavelength heat radiation, and the subsequent effects of these heat waves.

There are a number of other important upper atmospheric phenomena, and it is perhaps best to start by summarizing them as they would be encountered in the course of ascent from the ground (figure 1). After one passes through the troposphere, the stratosphere is reached at a height of about 12 km. At about the same altitude the primary cosmic rays, consisting mainly of very energetic protons as well as other nuclei, are strongly absorbed, producing the bewildering multitude of secondary particles the study of which forms one of the main branches of fundamental research in physics. The next region of importance is the ozone layer. At 70 km an unexpected constituent becomes apparent, namely sodium. Although present in only minute concentration this sodium makes an important contribution to air-glow effects. Some 10–15 km higher there are encountered for the first time regions in which there is an appreciable concentration of ions and electrons; that is to say, the concentration is large enough to influence the propagation of radio waves. This ionized region, known as the D region, can be a source of radio fade-outs at times, especially during periods of intense solar activity, when the ionization in the region is much enhanced.

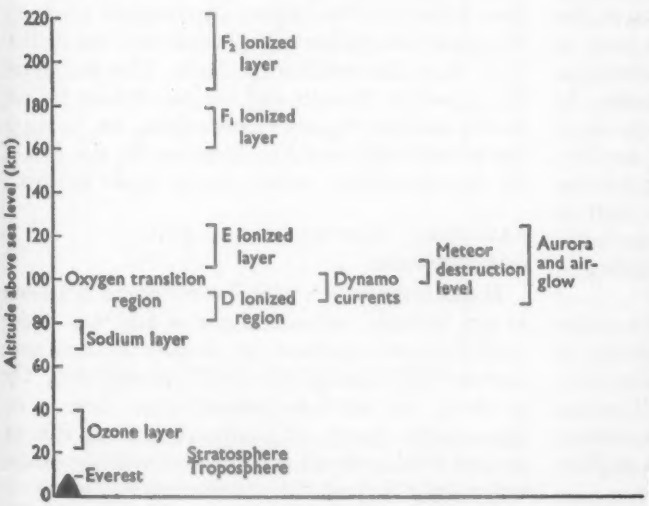

FIGURE 1 – *Schematic representation of the high atmosphere exhibiting the main regions of interest. (Note that the F_1 and F_2 ionized layers are shown separately. They are so only in daytime, merging at night.)*

At 100 km the threshold of several important regions is reached; at this height the pressure is only about 10^{-7} of that at ground level. The temperature, having passed through two peaks and a trough, ranging from 180° K at 80 km to 270° K at 50 km, is here about 240° K. The composition of the air, as far as the major constituents is concerned, is still much the same as at ground level; about four-fifths consists of molecular nitrogen and most of the rest of molecular oxygen.

At a slightly greater altitude an important change rapidly sets in—the oxygen becomes predominantly atomic. This produces considerable changes in the absorbing power of the oxygen for solar radiation, and also makes possible certain light-emission processes which

are important in determining the colour of the night air-glow.

Another technically important ionized layer is located between the 100 km and 120 km levels. It is a relatively thin (5–6 km) one, known as the E layer. Its electron concentration is considerably higher than that of the D region and the absorption very much less, so that the reflection of radio waves from the E layer plays an important part in long-distance radio propagation.

It seems probable that the main atmospheric currents which are responsible for the so-called steady lunar and solar magnetic variations flow in, or just below, the E layer. These currents result from the effect of atmospheric tidal motions on the E-region ionization, and they demonstrate the periodicity of these tides.

Many of the most interesting atmospheric light-emission phenomena arise from levels in the neighbourhood of 100 km. The night air-glow occurs throughout the year and shows little variation with latitude. It consists largely of the green and red line-emission from atomic oxygen, and band-emission from molecular nitrogen and from hydroxyl. The height of the emitting regions is probably not far from 100 km.

A more spectacular optical phenomenon is the aurora. This is much more intense than the night air-glow, and is concentrated in the so-called auroral latitudes—there is a maximum frequency of occurrence for the aurora borealis in a magnetic latitude of 67°, with a corresponding maximum in the southern hemisphere for the aurora australis. The auroral light includes strong emission at the wavelengths of the green and red oxygen lines, as in the air-glow, but the strong band-emission is from ionized, not neutral, molecular nitrogen. In the latitudes of most frequent occurrence the main light emission is from altitudes close to 100 km. At lower latitudes the much less frequent aurorae often occur at higher altitudes, some as high as 600 km. Magnetic storms are usually associated with auroral displays, and radio propagation is disturbed.

As pointed out earlier, the 100 km region is also the crematorium of most meteors. So many of them are volatilized near the same level that they produce a considerable concentration of ionization, often referred to as the sporadic, as distinct from the normal, E layer, which is at a slightly lower altitude.

There is still sufficient atmosphere well above 100 km to be of importance in many ways. Above 120 km the concentration of electrons and ions forming the E layer falls off, quite rapidly at first, but then begins to increase again, and by day reaches a new and larger maximum at about 160–170 km. This corresponds to the F_1 layer.

After passing above this altitude, the ionization soon ceases to decrease, and then increases again to form the very broad F_2 layer in which the electron concentration is ten times as great as the maximum in the E layer. At night the F_1 layer merges with the F_2, and there is an upward movement of the ionization to form the F layer which plays a vital part in long-distance radio propagation. At 160 km the atmospheric pressure is about 3×10^{-9} of that at ground level, while the temperature is perhaps 750° K. This upward trend in temperature almost certainly continues, so that well within the F_2 layer it probably exceeds 750° K.

Our knowledge about the upper atmosphere has been gained by a combination of direct and indirect observation. Until the last few years no direct methods were possible, but the recent remarkable developments in rocket propulsion have made it possible to carry instruments up to heights of as much as 200 km to make direct measurements of local conditions in the high atmosphere.[1] Because of the peculiar difficulties associated with use of rocket-transported instruments, the methods of observation have often to be very different from those which would be normally used in a laboratory measurement. Considerable ingenuity has been exercised in the design of rocket experiments and very important new results are now emerging. It is interesting and encouraging to note that, at least below 100 km, direct observations made by the use of rockets has largely confirmed the deductions from the indirect methods. The technique developed by Paneth and his co-workers for the micro-analysis of gases (ENDEAVOUR, **12**, 5, 1953) has proved very useful in investigating samples of air recovered from rockets sent to great heights.

PRESSURE, TEMPERATURE, AND COMPOSITION

If the composition of the atmosphere is known at any altitude, measurements of any two of the three quantities pressure (p), density (ρ), and temperature (T) enable the third to be deduced. Up to about 100 km it is probable that there is no appreciable change of composition from that at ground level, and this is consistent with the observations of p, ρ, and T by various methods.

[1] A detailed account of investigations of this kind will be found in the Proceedings of the Oxford Conference on Rocket Exploration of the Upper Air, to be published shortly.

The pressure and density have been measured directly up to altitudes as high as 200 km. The pressure is determined by suitable pressure gauges (bellows gauges for low altitudes and ionization gauges for the high ones) inserted on the sides of a rocket near the tail fins. Wind-tunnel tests have confirmed that such gauges measure the ambient pressures. The density is determined from the stagnation pressure, measured by a suitable pressure gauge at the nose of the rocket. The mean values of results obtained to date are given in figure 2.

The temperature variation has been determined by several methods. If the velocity, v, of sound can be obtained the temperature can be calculated from the relation

$$v^2 = \gamma RT/M$$

where R is the universal gas constant, M the average molecular weight of the air, and γ the ratio of the specific heats of the gas. The first way in which this possibility was utilized concerned the so-called anomalous propagation of sound. Intense sounds, such as those of gunfire, are often heard at great distances from the source, beyond an intervening zone of silence. This is because sound waves travelling at large inclinations to the horizontal are reflected by a high-temperature region, in which their velocity is increased, and thus return to earth at a distant point. The phenomenon is essentially similar to long-range radio propagation (see figure 3). The distance from the source to the point where the reflected rays, returning from different directions, are received gives the height of the reflecting high-temperature layer. Recently a more precise sound-ranging method has been introduced for use with rockets. At suitable heights grenades were ejected from a rocket in flight and exploded. The explosions were photographed and the arrival of the sound-pulses at each of five ground stations was accurately timed. From these observations the location of the explosion, the velocity of sound at different levels, and the distribution of atmospheric winds could be determined. An alternative method for measuring the speed of sound by rocket is from determination of the ratio of the pressures measured by two gauges located on the side of the rocket at different distances from the nose. This gives the Mach number of the flow past the rocket, and hence the speed of sound.

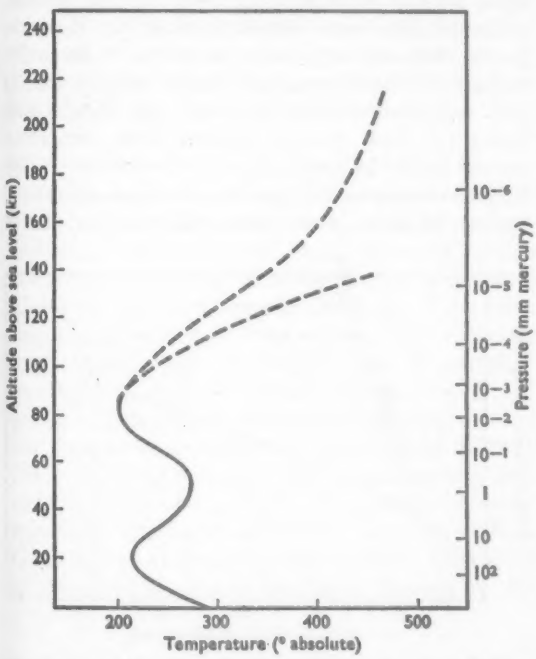

FIGURE 2 – *Pressure and temperature in the atmosphere as a function of height. The full line is obtained directly from the mean of rocket observations made at White Sands, New Mexico. Above* 100 *km there is uncertainty in deriving the temperature from the pressure and density, owing to changes in composition. The dotted lines indicate two results obtained on two extreme assumptions.*

Indirect evidence about the temperature distribution has been obtained from a study of atmospheric tides. It has been found from radio observations (see below) that the amplitude of the lunar tidal oscillations is greatly enhanced at the level of the E layer. The amplitude and phase of these oscillations at high levels are quite sensitive to the temperature distribution, and Weekes and Wilkes [1] were able to show theoretically that up to 100 km the general form must be that shown in figure 2.

Finally, it has been possible to obtain information about the temperature in the E and F layers by determination, by means of radio, of the variation of electron density with height. The scale height H, which is the distance above a given level at which the pressure has fallen to $1/e$ of its value at that level, is given by $H = RT/Mg$, where R, T, and M are as previously defined and g is the acceleration due to gravity. Assuming the atmospheric composition, the temperature T may be deduced if H is known. Allowance must be made for dissociation of the oxygen above 100 km, and possibly of the nitrogen also at higher levels.

Figure 2 illustrates our present knowledge about the temperature variation at different heights. Above 100 km there is considerable uncertainty

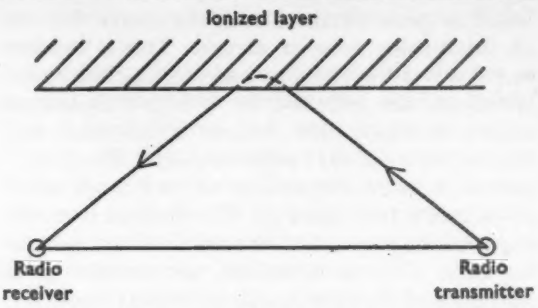

FIGURE 3 – *Illustrating the long range propagation of radio waves.*

due to uncertainty about the degree of dissociation of nitrogen. No direct measurements are yet available at these great heights.

THE IONIZED LAYERS

A great deal of research on the properties of the atmosphere in the E and F layers has been carried out by radio methods. The mechanism of long-distance propagation of radio waves is roughly as illustrated in figure 3, which shows a reflecting ionized layer. Furthermore, when radio waves of wavelength λ enter an ionized layer normally they are totally reflected at a level where the electron concentration n attains the value $\pi mc^2/e^2\lambda^2$, where e is the charge and m the mass of an electron and c is the velocity of light. By measuring the time-delay between vertical transmission of a ray of given wavelength and reception of the reflected wave, it is possible to determine the variation of n with height in a particular level until the observed wavelength is that for which n attains its maximum value in the layer. Further increase of wavelength then leads to complete penetration of the layer. Rocket methods now make it possible to trace the variation beyond this maximum. The method is to measure the local velocity of a radio wave by observation of the Doppler effect, due to the velocity of the rocket, on a radio signal transmitted from the rocket. The proportional Doppler shift in frequency is given by v/V, where v is the velocity component of the rocket in the direction of observation and V the phase-velocity of the radio wave transmitted from the rocket in the atmosphere round the rocket. V is given by

$$\left(1 - \frac{ne^2\lambda^2}{\pi mc^2}\right)^{-\frac{1}{2}} c,$$

where c is the velocity of light (total reflection occurs effectively where $V \rightarrow \infty$).[1]

For a long time data of great accuracy have been obtained by radio methods using many ground stations distributed over a wide range of latitude; rocket observations, on the other hand, have hitherto been limited.

As mentioned earlier, radio-sounding methods have given information about the temperature distribution and the tidal motions at great heights. The latter observations depend on careful studies of fluctuations observed in signals from the ionized layers. These layers are far from uniform. They have a granulated structure, and the motion of the granules, which are quite large, may be deduced from analysis of signal irregularities.

The ionized layers are produced by electromagnetic radiations from the Sun. A given ionizing radiation will produce electrons at an increasing rate per unit volume as it penetrates into denser and denser atmospheric regions, until absorption begins to be large; after this point it will decrease to zero, when the absorption is complete. The particular radiations responsible for the main ionized layers are still not identified with certainty. It is of interest to note, however, that by sending up in rockets counters sensitive to X-rays, definite evidence has been obtained that, at E-region levels, there are sufficient soft X-rays in the solar radiation to produce the E-region ionization. It was suggested some time earlier by Hoyle and Bates [2] that X-rays emitted from the solar corona might be responsible for the E layer. The F ionization may be due to ionization of atomic oxygen by short ultra-violet radiation, but this is

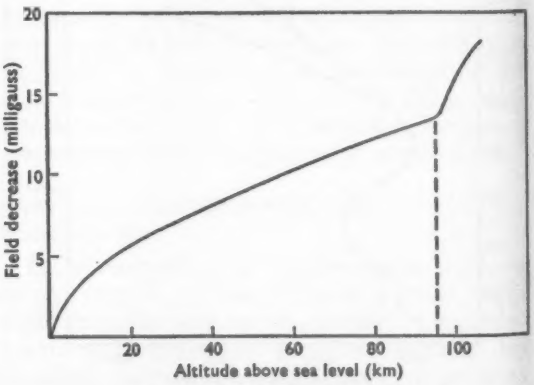

FIGURE 4 – *Observed decrease of magnetic field with height off the coast of Peru, using a rocket-borne magnetometer. The sudden increase in the rate of fall of the field at 93 km indicates the presence of a current layer at that altitude.*

[1] This formula neglects the effect of the Earth's magnetic field, which modifies the situation considerably.

far from certain. There is no doubt, however, from evidence obtained by observing the delay between obscuration of the solar disk and the onset of ionospheric changes during a solar eclipse, that the main layers are due to radiations travelling from the Sun with the velocity of light.

The tidal motion of the upper atmosphere exerts dynamical forces on the electrons and ions in the ionized layers, producing a current system, the nature of which is complicated by the Earth's magnetic field. According to the dynamo theory, first suggested by Balfour Stewart [3] as early as 1883, the tidal flow across the field produces a current in a direction perpendicular to each. The magnetic field at ground level includes a contribution from the field of this current system, and this will vary periodically with the tidal motion. These magnetic variations exhibit components varying with the lunar and solar tidal periods. Recent theoretical work has produced strong confirmation of the dynamo theory. Singer, Maple, and Bowen [4] performed a remarkable experiment with a rocket carrying a total-field magnetometer so that the variation of field with altitude could be measured. In passing through a current layer there should be a sudden decrease in field. Such a decrease was found to occur at an altitude of 93 km (figure 4), about the expected altitude of the base of the dynamo current layer.

THE AURORA AND AIR-GLOW

There is a clear correlation between the onset of an auroral display and the occurrence of disturbed conditions on the Sun. However, unlike the ionospheric-solar relation, there is a time-lag of one or two days between the onset of the solar disturbance and that of the aurora. This rules out solar electromagnetic radiation as the direct causative agency. The alternative is a stream of corpuscles. This cannot consist of charged particles of one sign, as their mutual repulsion would disperse the stream long before the Earth was reached. It is supposed that the stream is an ionized one containing protons and electrons in equal concentration. Strong evidence for the presence of protons in the incident stream has been afforded by the observations of Gartlein [5] and of Meinel [6] of broad hydrogen lines in the auroral spectrum. The broadening is due to a Doppler effect which would be expected if the lines were produced by fast incoming protons capturing electrons from atmospheric atoms, and if some of these electrons were captured into excited states. Radiation due to transitions from these states would account for the observations.

There are a great number of problems still unsolved concerning auroral phenomena. In some way the protons in the corpuscular stream must be speeded up near the Earth; if they had throughout their journey the speed calculated from the time-delay of auroral onset they would not be energetic enough to penetrate to the levels at which the auroral hydrogen lines are observed. The reason for the concentration of auroral effects in a narrow belt of latitude in each hemisphere is also far from clear.

The night air-glow is a more or less steady emission of light from the sky during the night, apart, of course, from starlight and any moonlight. It is much weaker than the aurora and involves much less energy. It is almost certainly due to transfer of some of the energy stored up from sunlight during the day into radiation in the far infra-red, visible, and near ultra-violet. Thus, during the day the sunlight dissociates molecular oxygen. Partial recombination of the resulting atoms during the night will involve processes in which light may be emitted. It is of interest to note that the yellow D lines of sodium are quite prominent in the air-glow spectrum, even though the proportion of sodium at its maximum concentration is less than 10^{-8} of the main atmospheric constituents. The intensity of emission is so high that Bates has suggested that an observable enhancement might be achieved by conveying a can of sodium to the required altitude by rocket and dispersing the metal there. A day air-glow has been observed by rocket methods at altitudes above 40 km where scattered light from the lower atmosphere is sufficiently weak. Detailed spectroscopic observation of this air-glow has not yet been carried out.

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Some early goldwork

CHARLES SINGER

Gold, almost unique among metals in being found only native, has been worked for many thousands of years. Some of the earliest pieces of surviving goldwork indicate not merely a high degree of craftsmanship but wide empirical knowledge of the physical properties of the metal, as Dr Charles Singer here demonstrates in discussing some famous examples.

The working of metals, even of gold, the easiest to handle, has always been left to specialists. Such a class implies a social surplus which could not exist until men began to grow some of their food, instead of merely hunting or gathering it. This great change of habit, the Neolithic revolution, involving some sort of permanent settlement, probably began in the seventh millennium B.C. Long before that, glittering grains of alluvial gold must have drawn the attention of wandering savages, but no gold object can safely be dated earlier than the fourth millennium B.C. By then, Neolithic barbarism was itself giving way, at several points in the Near East, to the urban revolution, that is to life in walled cities, of which the earliest known was at Jericho, *c* 6000 B.C. From such settlements arose small city-states, true civilizations, in the valleys of the Euphrates-Tigris and of the Nile. In both areas city-states had become knit together into empires before 3000 B.C., and by 2500 B.C. something similar was happening on the Aegean littoral. In all three areas the working of gold early reached a very high standard. The metal was first won by collecting grains from washed sand or mud, as is alluvial gold to this day, but true mining began remarkably early.

Gold was never a utilitarian substance. It was employed only for ritual or decorative purposes. Thus while the technology of copper was of far more practical importance than that of gold, it was on gold that the finest craftsmanship was usually expended. Nor is this surprising on other grounds, for gold is found always in the metallic state, and there were deposits of it within trading reach of Egypt and Mesopotamia (figure 1). An ancient Egyptian map of gold-workings survives (figure 2), but few ancient mining sites yield important archaeological results, since the miner necessarily destroys his predecessors' work. Nevertheless, we know that mining techniques were well advanced by the third millennium B.C., and that the art of ventilating mines was practised in the second millennium B.C. It is possible to reconstruct, with reasonable confidence, a central European copper-mine of about 1500 B.C. (figure 3). Long before then the great empires of the ancient east had organized the import of ores and of the fuel for working them.

Much gold came to Egypt from the Nubian desert, where there are traces of ancient diggings

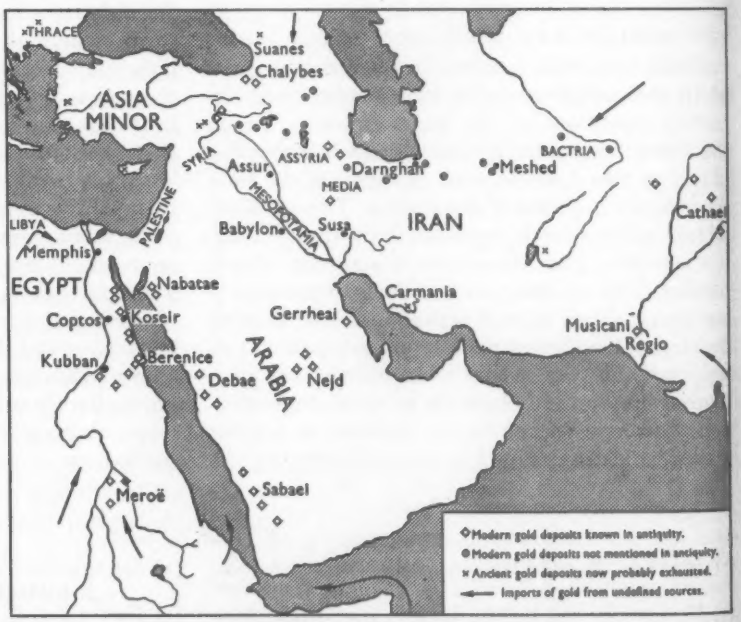

FIGURE 1 – *Sites of gold-workings in the Near East; only those verified by modern geology or archaeology are included. (Slightly modified from 'Metallurgy in Antiquity,' by R. J. Forbes. Leiden.* 1950.)

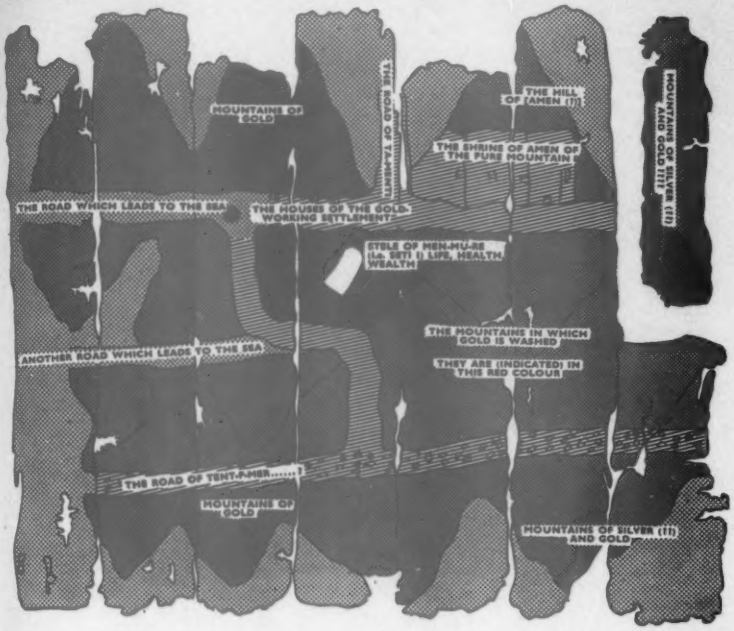
MOUNTAINS OF GOLD
THE ROAD OF TENT-AMEN
THE HILL OF AMEN (?)
THE SHRINE OF AMEN OF THE PURE MOUNTAIN
MOUNTAINS OF SILVER (?) AND GOLD (?)
THE ROAD WHICH LEADS TO THE SEA
THE HOUSES OF THE GOLD-WORKING SETTLEMENT
STELE OF MEN-MU-RE (i.e. SETI I) LIFE, HEALTH, WEALTH
THE MOUNTAINS IN WHICH GOLD IS WASHED
ANOTHER ROAD WHICH LEADS TO THE SEA
THEY ARE (INDICATED) IN THIS RED COLOUR
THE ROAD OF TENT-AMEN.....?
MOUNTAINS OF GOLD
MOUNTAINS OF SILVER (?) AND GOLD

FIGURE 2 – *Egyptian map on papyrus of gold mines in the Eastern Desert, with translations of the original inscriptions. c* 1300 B.C. (*Adapted from 'Egypt according to the Classic Geographers,' by J. Ball. Cairo.* 1942.)

still containing remains of washing-tables and grinding-querns. Nubia is said to have yielded annually some 300 kg of gold, and its name in Egyptian means 'land of gold.' Gold was found there in small irregular masses in quartz veins. Fragments of the rock were hammered into pieces, pounded in mortars, and ground to powder on querns. The powder was washed on wooden tables under a gentle flow of water which left the heavy metal particles behind. This gold dust was collected on sponges and then melted into a mass. Native gold liquefies at a temperature easily attainable in a charcoal fire with even the valveless bellows or the primitive blowpipes (figures 4, 5) of the ancient Egyptians. Pure gold melts at 1063° C, but native gold always has some other metal alloyed with it. Many such alloys melt at far lower temperatures than pure gold. Thus 18 per cent of copper reduces the melting point to 878° C, and there are other gold alloys that melt at even lower temperatures.

We cannot here attempt to trace the evolution of technical skill in handling metals, but may recall that the critical stage was reached in the fourth millennium B.C., when the connection between ores and metals was first grasped. By the end of the third millennium, mastery had been attained of the elementary metallurgy of gold, silver, copper, lead, tin, and certain other metals and their alloys, notably gold-silver (electrum) and copper-tin (bronze). An age of iron can hardly be said to have begun until the art of hardening it was mastered, about 1000 B.C., for until then iron was less useful than bronze.

Analyses of very early gold objects show that their metal always contains impurities such as silver, copper, antimony, and iron, which determine the colour. Both Egyptian and Mesopotamian technicians appreciated the variety of tints of gold, and they could even produce at will certain changes both in colour and surface texture. These skills were reached empirically and without any theory as to the nature of metals. We must content ourselves here with describing a few objects of

FIGURE 3 – *Reconstruction of a central European coppermine of about* 1500 B.C. (*From J. André, 'Bergbau in der Vorzeit.' Leipzig.* 1922.)

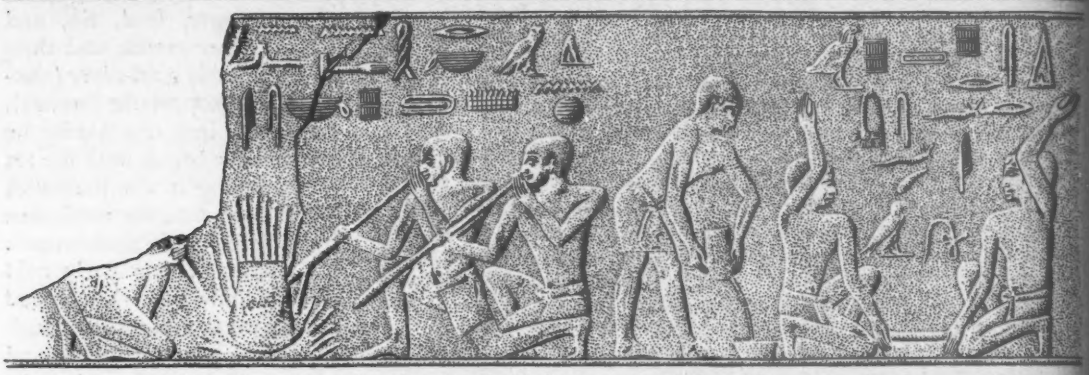

FIGURE 4 – *Egyptian gold workers. Blowpipes tipped with clay are used at the fire. The man pouring from a crucible protects his hands probably with small stones; the men on the right beat out the gold with stone hammers. From a tomb at Saqqara. c* 2400 B.C. (*Redrawn from 'Das Grab des Ti,' by G. Steindorff. Leipzig.* 1913.)

FIGURE 5 – *Primitive Egyptian bellows worked by the feet, from a tomb at Thebes. c* 1500 B.C. (*From 'The Life of Rekhmara,' by P. E. Newberry. London.* 1900.)

gold, or partly of gold, chosen as illustrating the technical expertness of these ancient craftsmen.

From Egypt of about 2400 B.C. comes a magnificent head of a hawk (figure 6). It is beaten entirely from a single sheet of gold, and finished by *repoussé* and chasing. The working was probably done largely with stone implements, but the chasing with hard copper or perhaps bronze tools. *Repoussé* is work in relief with hand-controlled punches from the back of sheet metal. To raise a pattern in low relief by blows underneath, with the decorated side resting on a yielding bed of bitumen or wood, is relatively simple, but to produce high relief or shaped figures by *repoussé* and chasing demands very great technical skill and knowledge. In this task there is a constant risk of cracking, and to avoid it there must be frequent annealing. Again, much skill and practice are needed to ensure that the thinning, consequent on hammering, is distributed evenly over the worked area. The two eyes of the hawk are formed by a single rod of obsidian, a hard, glassy substance, imported probably from Abyssinia. The rod passes right through the head and is polished in a spherical curve at each end. We know too little of the methods then employed to grind and polish so hard a medium. Powdered quartz embedded in a 'lap' or disk of copper has been suggested as the abrasive instrument. In any event, the production of this splendid piece involved the utmost skill and resource.

An Egyptian object of a much more elaborate type is shown on the coloured plate (figure 7), which is worth consideration for its own sake. The portrayal of contoured gold presents great difficulties to the block-maker and printer. To gain an impression of their success, the plate should be

FIGURE 6 – *Head of hawk, beaten from a single sheet of gold and finished by* repoussé *and chasing, from Hierakonpolis, Egypt. c* 2400 B.C. (*Redrawn from 'Bijoux et orfèvreries,' by E. Vernier. Cairo.* 1927.) (× ⅓)

FIGURE 7 (*opposite*) – *Part of lid of third and inmost coffin of Tutankhamun, last king of the Eighteenth Dynasty. c* 1[illegible] *His tomb is the only one of a Pharaoh that has been found containing all its funeral furniture.* (*From a painting by Nina Garis Davies.*)

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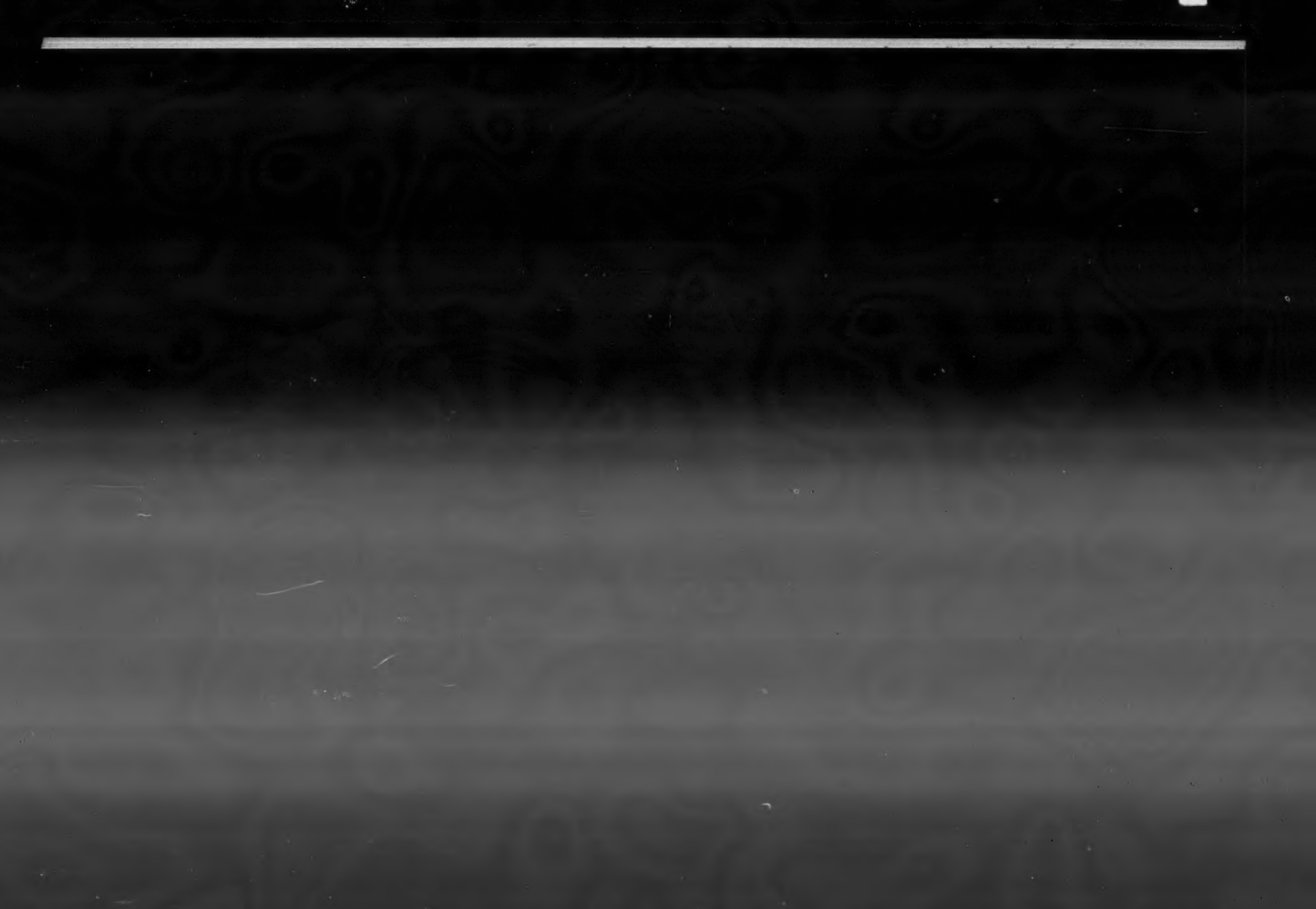

FIGURE 8—*Full view of inmost coffin of Tutankhamun.* (*Photo, Griffith Institute, Ashmolean Museum, Oxford.*) (× $\frac{1}{8}$)

examined in artificial light falling obliquely

The uniquely wealthy hoard of which this the gem was found in the Valley of the Tombs of the Kings at Thebes in 1926. The object itself was prepared to receive the body of Tutankhamun (died 1357 B.C.), last king of the great Dynasty XVIII, who died before he was twenty. His mummy was enclosed in three concentric coffins. This, the innermost, is like the others in the form of a portrait. It is of beaten gold, varying between 2·5 and 3·0 mm thick, raised from one large sheet, and wrought into high relief by direct hammering and *repoussé*. The decoration is *cloisonné*, that is to say, to the gold background has been soldered a pattern of gold wire, the spaces enclosed by the *cloisons* or partitions being filled with coloured materials.

The figure wears on the brow the royal insignia of vulture and cobra, the former with bill of ivory and eyes of obsidian, the latter inlaid with glass coloured to imitate turquoise, lapis lazuli, and cornelian. The hands hold the divine emblems of crook and flail, attributes of the god Osiris with whom, in death, the Pharaoh became identified. Face, neck, and hands are burnished, the feet draped (figure 8). The large collarette is adorned with bands of *cloisonné*, set with splendid coloured stones. The lower part of the body and the arms are enfolded by the protective figures of two vulture-goddesses with outstretched wings. They too are wrought in rich inlays of opaque polychrome glazes, lapis lazuli, cornelian, green felspar, and other stones. The remainder of the figure is covered with a feathered design and inscribed hieroglyphic texts.

The next object (figure 9) has not the beauty of the last two, but illustrates even better the versatility of ancient technicians in combining materials of very different kinds. It comes from a royal tomb of the first dynasty at Ur. It is of about 3000 B.C., and is one of a pair that originally supported something, perhaps the top of a small table. This representation of a goat had body, legs, and head of gold, and belly of electrum, all worked by *repoussé* and chasing, supported within by a wooden framework fastened with bitumen. The horns, the beard, and the dark locks of hair round the shoulders are blue and of lapis lazuli, the lighter locks of the lower part of the body are of shell, the eyes of lapis lazuli and shell. The tree to which the goat is attached is of gold, as is the stem that arises from the right shoulder. The rectangular base on which the creature stands is encrusted with pink and yellow sandstone and

FIGURE 9 – *'The ram caught in a thicket.' From a royal tomb of the first dynasty at Ur, in southern Mesopotamia, of before* 2500 B.C. *(Redrawn from 'Ur Excavations,' Vol. II, by Sir Leonard Woolley. London.* 1934.) *(By courtesy of the British Museum.)* (× ¼)

white shell. The striking character of this piece has suggested the title of 'the ram caught in a thicket' (Genesis, xxii, 13 ff). However, not only is it many centuries earlier than this passage, but the 'ram' is not caught but was tethered to the tree by a silver chain, which crumbled as the object was uncovered.

The civilization that arose in the Aegean about 2500 B.C. drew something from both Egypt and Mesopotamia and was probably the main foundation of the culture of classical Greece. Its influence spread far, reaching even Britain about 1400 B.C., as was demonstrated a few months ago at Stonehenge. Its greatest centre was in Crete and its cults were specially connected with the bull and

FIGURE 10 – *One of the Vapheio cups* (*c* 1600 B.C.) *now in the National Museum at Athens. (Redrawn from 'The Palace of Minos,' by Sir Arthur Evans. London.* 1930.) (× ⅔)

snake (figures 10 and 14), while its art is remarkable for vivid rendering of movement.

The famous pair of Vapheio cups of about 1600 B.C. (figure 10) are from a tomb near ancient Sparta. They are of beaten gold with riveted handles. The snaring and netting of wild bulls are most vividly portrayed on these cups (figure 11). One shows a drive of bulls along a wooded glen, where they are checked by a rope cradle stretched between olive-trees. From this the bull to the left has turned back and tossed one pursuer. His companion, a girl, has locked both her legs and arms around the animal's horns, making him powerless to strike. The bull to the right has avoided the barrier and galloped off. The bull in the centre is enmeshed. On the other cup a domestic cow decoys a wild bull. To the right he is nosing the cow's trail. In the centre she engages him in dalliance. To the left the herdsman, taking advantage of the situation, nooses the hind leg of the creature, who bellows impotently, 'as a dragged bull roareth when the young men haul him to the altar' (*Iliad*, XX, 404–5).

A second object from the Aegean area (figure 14) is of comparable date to the Vapheio cups and heralds a technical usage that had a very great future. This exquisite ivory statuette represents a priestess of the serpent-cult passing into a trance. She wears a tight gold belt, and her pleated skirt is decorated by a series of gold bands. She has gold armlets and in each hand holds a golden serpent, the body of which is coiled around the forearm. Locks of hair made of plaited wire once formed additional decoration round her head, and the holes of their attachment can still be seen. Such

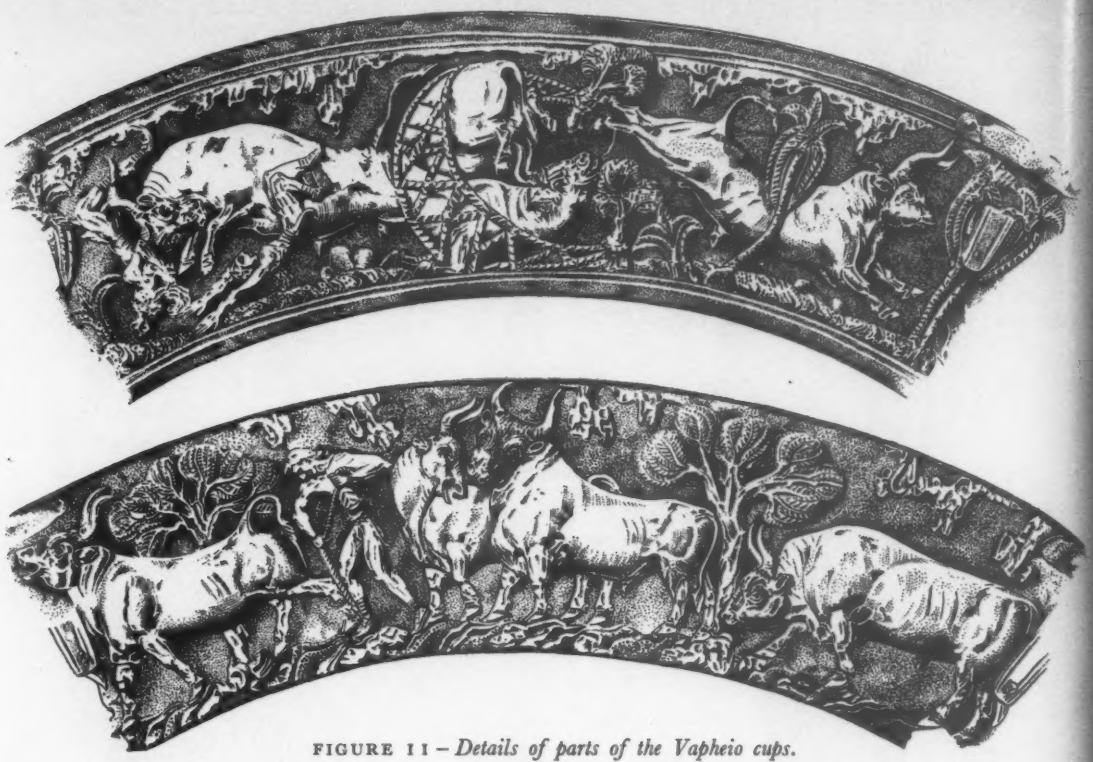

FIGURE 11 – *Details of parts of the Vapheio cups.*

works in ivory and gold were still specially admired by the Greeks of about a thousand years later. The most famous masterpieces of their Golden Age (fifth century B.C.) were the massive statues, about 40 feet high, of the goddess Athena in the Parthenon and of the god Zeus in his great temple at Olympia, both by Pheidias, the greatest of Greek artists. They were formed of an immense number of pieces of carved ivory mounted on a great wooden frame, with draperies and ornaments of gold. Both these masterpieces, the renown of which echoed through the classical world, have now utterly disappeared. Ivory and gold (chryselephantine) Greek work of the classic period is hardly to be found, but the ecstasy of the lovely serpent-priestess may suggest some of the emotional aura with which the images of the Greek gods filled their temples.

The formation of patterns of small grains of gold soldered to a background—'fine granulation'—is not known earlier than about 2050 B.C., when it was being practised in Egypt. The art spread to the Etruscans, who colonized Italy from Asia Minor about 900 B.C. and were ultimately absorbed by the Romans. Though the art of the Etruscans is not highly esteemed, they were extremely skilled technicians, especially with jewelry, and have never been excelled in their use of granulation. In some of the finest of this work the grains may be only 1/180th inch in diameter. Perhaps the best example is a golden bowl 4 inches in diameter (figure 12), with the pattern in double rows of grains of 1/80th inch in diameter, about 137 000 being used on this one work. The arrangement of grains and the soldering of such minute masses involve unsurpassed skill.

After Roman times the art of granulation was lost. Many efforts to recover it were made during the nineteenth century, but the modern technician could not repeat the delicacy and freedom of his ancient predecessor. The solder, however finely cut or filed, tended to flood the grains or wires, and the flux employed in the soldering was liable to boil up and displace the grains. At last the two difficulties were overcome, the first by dividing the solder into even more minute particles—chemically rather than mechanically—and the second by omitting the flux altogether. A copper compound, say the hydroxide, was used with a fish-glue to fasten the grains or wires in place.

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FIGURE 12 – *Etruscan gold bowl with granular decoration, said to come from Palestrina. c* 600 B.C. *Original size. (Victoria and Albert Museum, Crown Copyright.)*

FIGURE 13 – *Enlarged details of the above bowl executed in modern technique.*

When heated, the glue carbonized and the copper compound turned into copper oxide. The carbon then reduced the copper oxide to copper and disappeared, and a film of very finely divided copper was left in the joint. This alloyed with some of the adjacent gold, formed a solder, and joined the parts together. As a result of this discovery the modern technician can copy some of the finer Etruscan and Greek jewels and produce very beautiful original work. On the sample (figure 13) executed by this process, the largest grains measure 1/50th inch, and the smallest 1/200th inch. The work is so delicate, although strong, that daylight may be seen between the grains.

ACKNOWLEDGMENT

Much of the text of this article is based on information contained in the relevant chapters of 'A History of Technology' (The Clarendon Press, Oxford), the first volume of which is to be published shortly. All the illustrations, except figure 1, are taken from the same work, by kind permission of the Delegates of the Press.

FIGURE 14 – *Ivory and gold statuette from Crete. c* 1500 B.C. *Height* 6½ *in. (Redrawn from 'The Palace of Minos,' by Sir Arthur Evans. London.* 1930.)

The Alembic Club

JAMES KENDALL

The Alembic Club of Edinburgh is famous for its reprints of classical chemical investigations, including English versions of Mayow's remarkable *Tractatus Quinque Medico-physici* and of Cannizzaro's *Sunto di un corso di filosofia chimica*. Under a new arrangement the affairs of the Club are to be administered under the aegis of the Royal Society of Edinburgh, but this change will expedite, not interrupt, the publication of further reprints in this important series.

In 1889, the staff of the chemistry department of the University of Edinburgh consisted of Professor Crum Brown and five poorly paid assistants. These five assistants, on 29th October, met in the departmental library—a dark and dismal chamber of execrable proportions—and came to a memorable decision: they instituted the Alembic Club. The objects of this club, detailed on the first page of its first minute-book, were:

1. To secure the better recognition of the University of Edinburgh as a centre of chemical research.
2. To encourage the study of the history and literature of chemistry.
3. To promote by individual and collective effort the professional advancement of its members.

Many similar clubs with similar aspirations have, no doubt, been formed elsewhere at various periods, fading into oblivion after a few years. The Alembic Club, however, has flourished for more than half a century and, following a recent reorganization, will presumably flourish in perpetuity. Primary emphasis will here be laid on the accomplishment of its second object, whereby—in the words of one of its members—an unassuming body was destined to play a useful part in bringing important historical material connected with chemistry within the reach of interested readers.

The five original confederates, in order of seniority, were John Gibson, Leonard Dobbin, Hugh Marshall, James Walker, and Alexander Smith. At their first ordinary meeting, held on 19th November, 1889, Dobbin (then aged 31) was appointed secretary—an office he held for fifty-seven years. Thirteen formal rules for the regulation of the club's activities were approved; one of these fixed the maximum number of ordinary and corresponding members at thirteen. Further disregard for superstition was shown in Rule 10, appointing the fifteenth day of December as the date on which the modest annual subscription was due. This date was carefully calculated as the thirteenth day of the thirteenth month of a year comprising thirteen months of twenty-eight days each. The Club's rule thus anticipated a reformed calendar that has come up for serious consideration recently, although 'the question of the disposal of the odd day (two in leap year), not coming within the purview of the members, was left to others for decision.'

Another rule required each member on promotion to professorial rank 'to entertain his fellows at the festive board'; this was duly observed on six auspicious occasions, as will be noted later.

The main business of early monthly meetings consisted of reports by each member on his own research and on papers of particular interest comprised in that section of current chemical journals assigned to him; in subsequent minutes discussions on a vast number of such reports are detailed. On 21st January, 1890, however, Leonard Dobbin broached a new proposal—the desirability that the club should undertake to issue a series of small books at a low price containing reprints of classical chemical investigations. 'A good deal of conversation took place as to the probable cost of such an undertaking. No definite motion was made, but the general idea was that the matter might be worth pursuing further.' With typical Scots caution, in point of fact no action was taken during the next three years.

These years witnessed a number of changes. On 28th October, 1890, it is minuted: 'That this meeting has heard with pleasure of Dr Alexander Smith's appointment as Professor of Chemistry in Wabash College, Indiana, and hereby expresses the hope that this may be but a step towards that eminent position for which his connection with this Club has so thoroughly fitted him.' Alexander Smith's career in the United States more than justified this optimism. In 1894 he became professor of chemistry in the University of Chicago,

and in 1911 head of the department of chemistry in Columbia University, New York, and president of the American Chemical Society. He maintained an active interest in the Alembic Club until his death in 1922.

On 17th February, 1891, Ralph Stockman was admitted to ordinary membership, and monthly reports and discussions on current chemical investigations continued until 18th March, 1892, when 'none of the members having any points of interest or any business to bring forward, the Club held its first musical evening instead.' On 18th October, 1892, two resolutions were moved and adopted:

1. 'That the Club congratulates Dr John Gibson on his preferment to the chair of chemistry in the Heriot-Watt College. Item, that Dr Gibson entertain the Club to a banquet in commemoration.' Succeeding William Henry Perkin at the Heriot-Watt College, Edinburgh, Gibson occupied this chair until his death in 1914. He is still remembered in organic chemistry as participator in the Crum Brown and Gibson rule.
2. 'That the Club sympathises with itself on the transference of Dr Walker from ordinary to corresponding membership.' Walker had left for University College, London, to work under Ramsay, with whom he had made acquaintance at the British Association meeting at Leeds in 1890 during the historic debate on the revolutionary ideas of Van 't Hoff and Arrhenius. Walker and Ramsay were introduced by Ostwald, who pronounced their names in German fashion, and they continued to converse in German for a long time before discovering that they were brother Scots. The association of these two chemists considerably accelerated the acceptance of the theories of osmotic pressure and ionization in Great Britain.

To return to the Alembic Club: 1893 proved a decisive year in its development. At a meeting on 13th February, Dobbin, tired of waiting for approval of his suggestion regarding the issue of reprints, bluntly informed his fellow-members that he had arranged for Joseph Black's world-renowned dissertation of 1755, 'Experiments upon Magnesia Alba, Quicklime, and some other Alcaline Substances,' to be set up for printing entirely on his own account, and wished permission to use the name of the Club in entitling it the first of a series of Alembic Club publications, on the understanding that he should bear all financial responsibility. 'After some discussion the Club agreed to this proposal.'

There certainly does not seem to have been any initial enthusiasm on the part of his colleagues with respect to this rash experiment, but Dobbin pressed forward undaunted. On 15th July, he reported not only that Alembic Club Reprint No. 1 had already sold 'about 60 copies,' but that No. 2, 'Foundations of the Atomic Theory,' comprising papers by Dalton, Wollaston, and Thomson, for which also he made himself financially responsible—was 'newly published and selling slowly.' In 1894, three additional reprints were issued, two by Dobbin and one by Walker, whose appointment as professor of chemistry at University College, Dundee, in that year was followed by the prescriptive extraordinary meeting of the Club for 'prandial entertainment.' In 1895, no fewer than six new reprints appeared, three sponsored by Dobbin, two by Marshall, and one by Walker. Sales were still meagre, and it did not look as if income could possibly balance expenditure for many years to come. Nevertheless, the reprints were receiving very favourable notices in chemical reviews, teachers of chemistry and chemical historians both in Great Britain and in America were evincing increasing interest in them, and Crum Brown had offered to assist in financing the publication of a more ambitious project—an English version of Mayow's remarkable work *Tractatus Quinque Medico-physici*, which anticipates by a century many of the discoveries of the 'pneumatic period.' This volume, translated by Dobbin from the original Latin and thus made generally available to chemists for the first time, finally came off the press as Alembic Club Reprint No. 17 in 1907.

By that time the tide had turned, and all the early reprints had begun to make a profit. This profit was deliberately restricted to a minimum by keeping the selling price as low as possible, and sums accruing to individual sponsors were essentially devoted by them to restocking particular numbers as these neared exhaustion. Furthermore, each member at or before his decease gave all his future rights to the Alembic Club, which accordingly ultimately became the sole owner of the entire series of 21 reprints tabulated at the end of this article. By March 1953 the total sales exceeded 33 000. Leonard Dobbin's gamble had been triumphantly vindicated; a group of amateurs had succeeded in a publishing venture which seemed, at its inception, doomed to failure.

No additions to the Club's membership were made between 1891 and 1929. In 1897, Ralph

Stockman was appointed professor of materia medica in the University of Glasgow—a position he held for forty years—and another dinner celebrated the event. In 1908, a delicate situation arose; the veteran Crum Brown (who had actually attended the celebrated Karlsruhe Congress in 1860, when Cannizzaro cleared the mist from chemistry by reintroducing Avogadro's hypothesis) at last retired from the chair of chemistry at Edinburgh, and James Walker of Dundee and Alexander Smith of Chicago were placed on the short list of candidates for it. The choice between them was in the hands of seven curators of patronage—three elected by the University Court and four by the Town Council—and at that time it was customary for each candidate to pay a personal call on each curator in advance to solicit his support. This custom sometimes led to much back-stage manœuvring, but Smith and Walker, pledged by the Alembic Club 'to promote by individual and collective effort the professional advancement of its members,' astonished the curators by paying their calls arm-in-arm together, each urging the claims of the other. When the final vote went in favour of Walker by 4 to 3 Smith probably considered he had won his case.

Walker's vacant chair at Dundee immediately fell to a third club member, Hugh Marshall, whose brilliant discovery of the persulphates had gained him fellowship of the Royal Society some years previously. Unhappily, he died of typhoid fever in 1913.

On Sir James Walker's own retirement in 1928, full of honours after twenty years spent in 'securing the better recognition of the University of Edinburgh as a centre of chemical research,' he was succeeded by the author of this article, one of his own students who after graduation had migrated to Alexander Smith in America and who was privileged to become a member of the Alembic Club on his return. As recorded in the minutes, 'a further auspicious occasion terminated with the advent of closing time.' Two more of Walker's students were subsequently elected — Irvine Masson, professor of chemistry at the University of Durham, in 1932, and Oswald James Walker, lecturer in chemistry at University College, London, in 1937.

Through all the above period, the guiding spirit of the Alembic Club was Leonard Dobbin, whose long service to the University of Edinburgh ended on his retirement with the rank of Reader in 1924. He maintained his sedulous interest in the club, however, until his death in March 1952 in his ninety-fourth year. In 1946 frailty of body—his mind remained alert and unimpaired—forced him to demit the office of secretary, but the author (who took over from him) constantly consulted him on questions of policy until the close. He became apprehensive towards the last about the future of the Alembic Club, and his successor knew that he was acting just as Dobbin himself would have wished when, with the concurrence of the other two surviving members, he asked the Council of the Royal Society of Edinburgh to accept the entire assets of the club and the responsibility for the continuance of its series of reprints.

This offer was cordially accepted, and rules for the administration of the Alembic Club Fund under the aegis of the Royal Society of Edinburgh have since been drafted and approved. The Alembic Club, fortified by the senior officers of the Society, will persist as a self-perpetuating body, and Norman Feather, professor of natural philosophy in the University of Edinburgh, and John E. Mackenzie, a former collaborator of Leonard Dobbin, who succeeded him as reader in the department of chemistry, have been added to its membership. It is planned to award quinquennially, if funds are sufficient, an Alembic Club Prize of £50 to a distinguished historian of science, and to hold Alembic Club Lectures at unspecified intervals. The first of such lectures will be formally entitled the Leonard Dobbin Memorial Lecture.

The primary aim of the club, however, will be to continue the existing Alembic Club Reprints, as listed below, and to extend the series.

ALEMBIC CLUB REPRINTS

1. *Experiments upon Magnesia Alba, Quicklime, and some other Alcaline Substances.* Black.
2. *Foundations of the Atomic Theory.* Dalton, Wollaston, and Thomson.
3. *Experiments on Air.* Cavendish.
4. *Foundations of the Molecular Theory.* Dalton, Gay-Lussac, and Avogadro.
5. *Extracts from* Micrographia. Hooke.
6. *The Decomposition of the Alkalis and Alkaline Earths.* Davy.
7. *The Discovery of Oxygen, Part I.* Priestley.
8. *The Discovery of Oxygen, Part II,* Scheele.
9. *The Elementary Nature of Chlorine.* Davy.
10. *Researches on the Arseniates, Phosphates, and Modifications of Phosphoric Acid.* Graham.
11. *Essays of Jean Rey.*
12. *The Liquefaction of Gases.* Faraday.
13. *The Early History of Chlorine.* Scheele, Berthollet, de Morveau, Gay-Lussac, and Thenard.
14. *Researches on the Molecular Asymmetry of Natural Organic Products.* Pasteur.
15. *The Electrolysis of Organic Compounds.* Kolbe.
16. *Papers on Etherification, and on the Constitution of Salts.* Williamson.
17. *Medico-physical Works.* Mayow.
18. *Sketch of a Course of Chemical Philosophy.* Cannizzaro.
19. *The Foundations of the Theory of Dilute Solutions.* Van 't Hoff and Arrhenius.
20. *Prout's Hypothesis.* Prout, Stas, and Marignac.
21. *On a New Chemical Theory, and Researches on Salicylic Acid.* Couper.

The Montpellier Botanical Garden

HERVÉ HARANT

The botanical garden of the University of Montpellier is one of the oldest in Europe, dating from the late sixteenth century, and with it are linked the names of many men eminent in botany, pharmacy, and medicine. During the last war, it suffered grievously from both direct damage and unavoidable neglect, but it is now being restored, giving promise of a future as fruitful as its illustrious past. Professor Harant describes its history and present condition.

Since the twelfth century, students from all parts of Europe have met at the famous medical school at Montpellier that grew up under the influence of the Arabs, the Jews, and the Christians of Salerno. In 1220, a bull of Cardinal Conrad, papal legate in Languedoc, consolidated the school into a university. With the spread of medical knowledge the study of natural history became an important part of the teaching at Montpellier, as is shown by documents of the time. Arnaud de Villeneuve, regent of the Faculty in his time; Michel Nostradamus, who received his doctorate in 1529; and Jean Ruel (1479–1537), all visited Montpellier to collect plant specimens even before botany had begun to be taught there. Nevertheless, from 1550 certainly, and most probably from an earlier date, regular botanical work was going on, as can be seen from article 6 of the *Arrêt des Grands-Jours* (Béziers, 1550): '*Seront tenus les dits Chanceliers, Docteurs et Conseillers, députer l'un d'entre eux Docteur des plus idoines et suffisant pour lire aux écoliers et montrer oculairement les simples; depuis la Fête de Pâques jusques à la fête de la Saint-Luc, et lui constituer salaire compétant à payer par le dit Trésorier, et pour chercher les dits simples en la dite ville de Montpellier et lieux circonvoisins, seront, aux dépens de la dite bourse, députés un ou plusieurs, lesquels y vacqueront le plus diligemment que faire se pourra.*' Many well known men distinguished themselves at Montpellier: such were Rondelet, who is remembered as much for his botanical work as for his zoology, Lobel, Clusius, Bauhin, Dalechamp, and Rabelais and his co-pupil Fuchsius (after whom the fuchsia is named). It seems probable that the medical students had at that time only a small *hortulus*, of which traces have been discovered in the courtyard of the old medical school, the site now occupied by the young and flourishing faculty of pharmacy. In due course, a botanical garden became an indispensable adjunct to a medical course to which students were attracted from all parts to Languedoc, both by the reputation of the teachers and by the richness in simples of the Mediterranean flora. The Republic of Venice had already established gardens at Padua in 1545, and Cosmo de' Medici founded those at Pisa in the following year; Bologna had its gardens in 1568, Leyden in 1577, and Leipzig two years later. In 1593 Henry IV of France commanded Pierre Richer de Belleval (1558-1623) to set up a botanical garden at Montpellier; the early appearance of these gardens has come down to us in the form of an etching attributed to Richer de Belleval himself, which is preserved in the library of the garden (figure 1). Although a part of the original garden was destroyed in 1622 during the wars of religion, there remains to this day the terraced mound dating from Richer de Belleval's time and known to all as 'The Mountain.'

For some two centuries, the garden underwent no substantial change. Some of those in charge of it during this period are now almost forgotten—Martin Richer de Belleval (1632–64), the founder's nephew, the four Chicoyneaus, Imbert (1760–85)—but many others left their mark on the history of science. During the three years in which he held the post of director, Pierre Magnol (1694–7) proposed the systematic grouping of the plants by families. He was unable to undertake the reorganization involved, but his own high reputation enhanced that of the garden. He himself must be considered an important forerunner of Linnæus in the setting up of a systematic classification, and among his pupils were Joseph Pitton de Tournefort and Antoine de Jussieu. François Boissier de Sauvages, in charge of the garden from 1740 to 1758, himself worked out a system of botanical classification based on the vegetative parts; he also ventured into the medical field in proposing a new classification of diseases. De Sauvages was followed by Antoine Gouan (1794–1803), who, however, became old and ill

before he achieved full control; he in turn gave place to Auguste Broussonet (1761–1807). Broussonet, at once botanist and zoologist, politician and traveller, introduced the ginkgo (*Ginkgo biloba*) and the mulberry (*Morus nigra*) into France; he brought new life to the garden by the erection of the great orangery and a temperate house, and by constructing in the grounds of the botany school a canal for the cultivation of aquatic plants. At his death at the early age of 46, Broussonet was succeeded by the great Pyrame de Candolle. Although de Candolle spent only nine years (1807–16) in charge of the garden, his influence was profound. Many important constructional works were undertaken during his term of office, notably the building of a hothouse and the forestry school, the digging of irrigation channels, and the setting up of the great botany school whose ground-plan remains unchanged to the present day. Dunal, de Candolle's pupil, acted as superintendent of the garden during a three-year interregnum (1816–19), but never became director, because he was not appointed to the chair of the Faculty of Medicine. He was followed by Alyre Raffeneau-Delile (1778–1850), whose work on the flora of Egypt is well known. To him we owe the beautiful *Nelumbium* in the lake in the English garden, and several interesting cycads in the glasshouses.

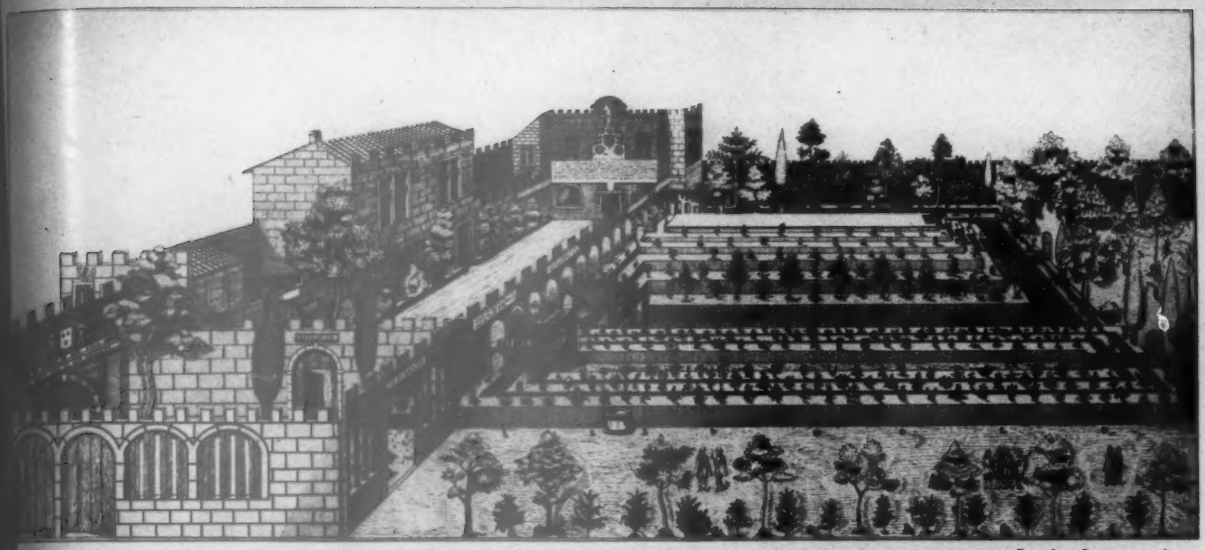
During the second half of the nineteenth century the post of director was held by three famous scientists. Charles Martins, director from 1851 to 1879, set up a school of medicinal plants, and constructed the English garden and the large cold-house which bears his name. He worked with equal success in the fields of meteorology, geophysics, botany, and zoology. Jules-Émile Planchon studied botany at Kiev and at Ghent before returning to direct the botanical gardens of his native town. He built a propagating house, but is chiefly remembered for his great part in the fight against the *Phylloxera* pest of the vine. Maurice Granel, during his 44 years of office (1889–1933), carried out great changes in the layout of the garden, with the help of the head gardener, Jules Daveau, a master of his craft.

During the nineteenth century, the teaching of natural history was divided between the Faculty of Medicine, the Faculty of Science, and the School (now Faculty) of Pharmacy. This explains how it came to pass that many notable botanists have worked in the garden in addition to the directors, who are traditionally professors in the Faculty of Medicine. We must not forget, for example, Charles Flahault, founder of the Institute of Botany. In our own day, my immedia predecessor, Professor Galavielle, kept the gard going during the difficult times which followed t war and the occupation.

Many changes in the layout of the garden a planned for the near future, and a great new Ins tute of Botany is already under construction. T present plan is shown in figure 5. With a to area of some 15 acres, the garden extends along north-south axis and is divided into two parts the Mountain, which runs east and west. T main avenue on the Mountain, where we fi various plants dating back to the origins of t garden, runs up to the Director's Lodge, in fro of which there stands a fine old Judas tree (*Cer siliquastrum*) whose lower branches live on, thou the trunk is dead and mildewed. The academ building is clothed with the beautiful green folia of *Wistaria sinensis*. Nearby stands the recent erected statue of Pierre Richer de Belleval, t founder. Close to de Candolle's great school sta the orangery, Planchon's glasshouse, an orch house, and a propagating house. In spite of the w we still have several fine plants here: *Damma Callistemon*, *Vanda*, *Pandanus*, *Pterospermum*, a various mesembryanthema and cycads. In t absence of many foreign plants at present lost us and awaiting reintroduction, our borders a planted with examples of the Mediterranean flo —terebinth (*Pistacia terebinthus*) and mastic tre (*Pistacia lenticus*), helianthema, cisti, and ma others. Thyme (*Thymus*), lavender (*Lavandul* juniper (*Juniperus*), and kermes oak (*Quercus coc fera*) are also to be seen. Elsewhere in the gard are collected plants of the coastal regions: stoc (*Matthiola*), sea-heath (*Frankenia pulverulenta*), *Co Statice*, and the various succulent Chenopodiace of the salt-laden soils known locally as *sansouire*.

Round de Candolle's garden there stand bu of many famous directors and naturalists who ha worked in the garden. Near Raffeneau-Deli ginkgo tree is the *Tombeau de Narcisse*; this is n dedicated to the beautiful youth of Greek myth logy, but commemorates the stepdaughter 'N cissa' (Mrs Temple) of the English poet Edw Young; she is said to have died at Montpelli though she was in fact buried at Lyons. Of t *Tombeau* there remains today only a Latin inscr tion, but the place has been nevertheless one pilgrimage for many, including the French writ André Gide and Paul Valéry.

Passing beyond the Mountain into the mod part of the garden, we observe a magnific nettle-tree (*Celtis australis*), the majestic '*falabre*



IGURE 1 – *An etching attributed to Richer de Belleval, showing the garden at the end of the sixteenth century. In the foreground, an venue of laurels and pomegranates* (Punica)*; among the figures is Richer de Belleval demonstrating to his pupils. On the left, the ntrance to a nursery of foreign trees. In the centre, the terraces of 'The Mountain' with medicinal plants.*

FIGURE 2 – *Bust of J. E. Planchon, in front of the orangery.*

FIGURE 3 – *Bust of Charles Martins.*

FIGURE 4 – *Main avenue of 'The Mountain.'*

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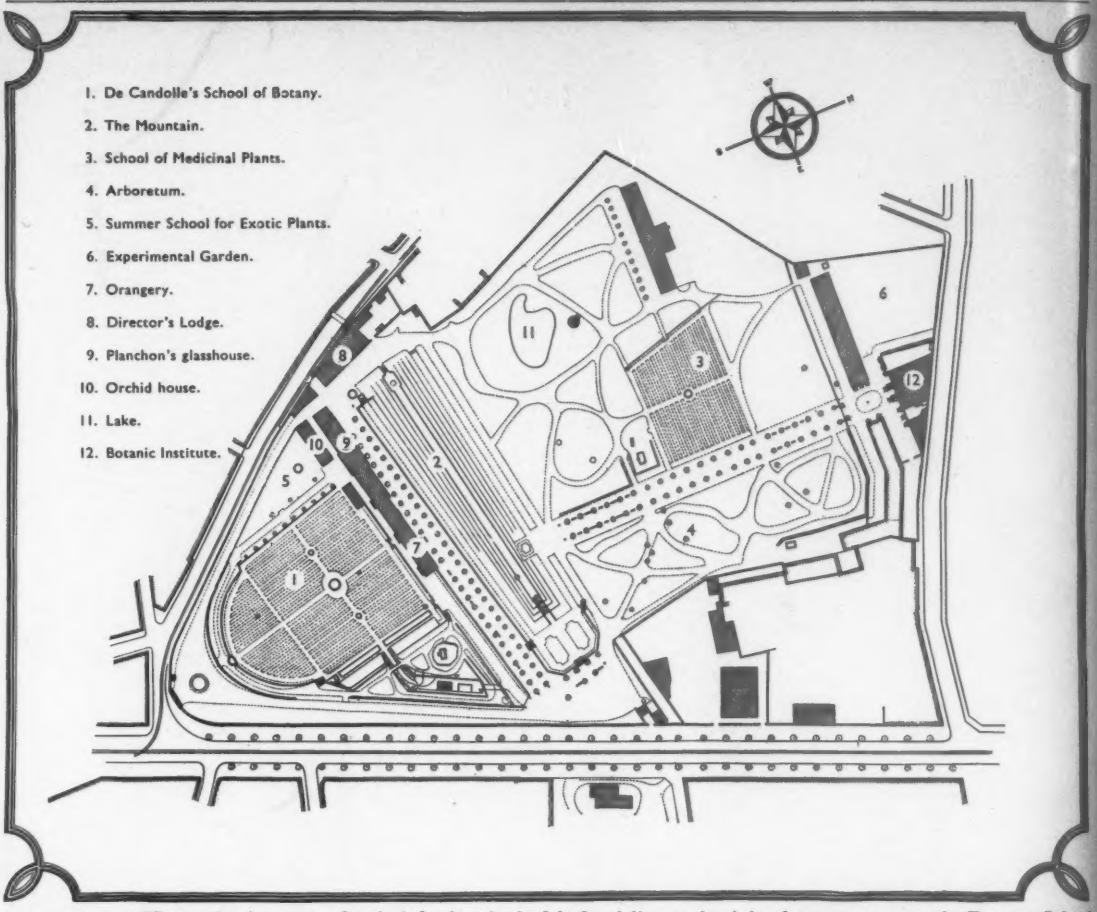

FIGURE 5 – *The garden in* 1942. *On the left, the school of de Candolle; on the right, from east to west, the Forestry School, the School of Medicinal Plants, and the English Garden. This* 1942 *plan will be profoundly modified in the N.N.W. sector when the construction of the new Botanical Institute is finished. There will also be a modern glasshouse near the lake. The Botanical Institute will house the chairs of botany of the Faculties of Science and Pharmacy, as well as the chair of Natural History of the Faculty of Medicine. It will also provide accommodation for the technical and administrative services.*

of Mistral. On the right stands the School of Forestry, founded by de Candolle and enlarged by Granel in 1910. Here there are many fine trees, notably an imposing elm, *Zelkowa crenata*, several American locust trees, and some Osage oranges. Leaving the Forestry School, we cross the broad avenue named after de Candolle. This is bordered by horse-chestnut trees (*Aesculus*), and leads from the Institute of Botany to a statue of Rabelais set up in 1922. We next pass into the School of Medicinal Plants, with its fine collection of 800 species, then to a series of acclimatization beds surrounding an old well. Finally, we enter the English garden with its lotus lake. This lake is covered in the season with a carpet of the green leaves of these beautiful plants (*Zizyphus lotus*). Other aquatic plants surround them, less beautiful perhaps, but no less interesting; we may mention the water-lilies, sedges, and bulrushes. Recently we have here introduced members of the flora of the Camargue, an interesting ecological association.

As we have looked back on the illustrious past history of the garden, so we must look to the future to restore its status, grievously damaged during the war. We hope to celebrate the construction of the new Institute of Botany by re-planning the garden, restoring the paths, improving the soil, and rebuilding the damaged glasshouses. We intend to set up ecological groupings, following the example of Galavielle's Mediterranean garden; to start experimental plots for studies on physiology and genetics; to introduce new specimens from the tropics; and to improve our techniques of cultivation and irrigation.

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Semiconductors

KARL K. DARROW

In both practical application and theoretical study, semiconductors are of comparatively recent advent. In the last few years, however, rapid progress has been made in both directions. Semiconductors are the essential components of transistors which, being small and light and requiring comparatively little power, have already found many important uses in electronic equipment. Theoretical studies have led not only to some understanding of the nature of semiconductors but have thrown light on the structure of solids in general.

The word semiconductor ought to mean half a conductor, but, among the many definitions of it that have been made, this is one that seems never to have appeared. Originally, semiconductors were defined as substances that conduct much worse than metals but markedly better than insulators. Later, they were defined as substances which become more conductive with rising temperature. This is a definition that sets them apart from metals; it is still fairly satisfactory, but no longer applies to all. Some physicists have defined them as substances that conduct only because of the impurities they contain: this is now not broad enough. As a definition suitable for present purposes, I suggest that semiconductors should be regarded as electronic conductors in which the number of free electrons varies with the temperature. As will be seen later, this also will require modification—for instance, to take account of conduction by holes.

Semiconductors used to be regarded as oddities of nature, undoubtedly worth the attention of physicists but of little practical importance in comparison with metals. In two excellent textbooks of electricity, one published in 1912 and the other in 1916—Starling's and Pidduck's respectively—the word semiconductor is not to be found in the index. All this is now changed. The subject index of the 1952 volume of 'Physics Abstracts' shows three times as many papers listed under the heading of semiconductors as under the heading of metals. The change is partly due to two stimuli coming from applied physics: the study of rectifying junctions between semiconductors and metals, and the recent invention of the transistor. It is interesting that in some respects—though not in all—semiconductors now offer better verifications of certain fundamental theories than even the metals do.

Electronic conductors include both the metals and the semiconductors. In an electronic conductor there are innumerable bound electrons that do not concern us in the present context unless and until they are set free; there are also free electrons. The free electrons form an electron-gas, the particles of which move hither and thither in the substance with the enormous speeds of thermal agitation. When an electric field is applied, the electron-gas starts to drift through the substance: it becomes an electron-wind. This electron-wind is the electric current. The wind-speed or drift-speed is proportional to the field-strength, except under extreme conditions to which no reference will be made in this article. The ratio of drift-speed to field-strength—in other words the drift-speed at unit field-strength—is a fundamental quality of the substance. We call it the mobility. Here must be introduced two symbols: μ for the mobility, and $\mathcal{N}$ for the number of free electrons per unit volume.

The values of μ and $\mathcal{N}$ may be found by performing a famous experiment which shows what is called the Hall effect. It was in 1879 that Hall first observed the effect: one regrets that this was twenty years before the Nobel prize was founded. Hall was also twenty years in advance of the electron theory, and therefore described his results in words other than those that will be used here.

Imagine a ribbon of an electronic conductor lying in the plane of the paper (figure 1) with a battery to drive a current along it. Let its positive end be at the right; by the old and fixed convention, the current is then from right to left, which is the opposite sense to that of the electron-wind. The equipotential lines will be at right angles to the length of the ribbon, as CD in figure 1. Let two

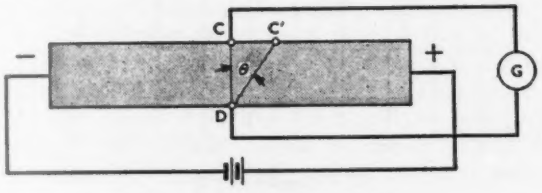

FIGURE 1 – *The Hall effect.*

electrodes be applied to the sides of the ribbon at opposite ends C and D of such an equipotential line, and let them be connected through a galvanometer. No current flows through the galvanometer. But now let a magnetic field be applied at right angles to the plane of the ribbon, pointing (let us say for definiteness) through the plane of the paper towards the onlooker. Now a current does flow through the galvanometer. The line CD is no longer an equipotential line. The equipotential line is now tilted clockwise through an angle θ: it is C′D of the figure. One may annul the current through the galvanometer by introducing an electromotive force of appropriate size and sign into the galvanometer circuit (the conventional way), or by displacing the electrode from C to C′ (the way best suited to exposition).

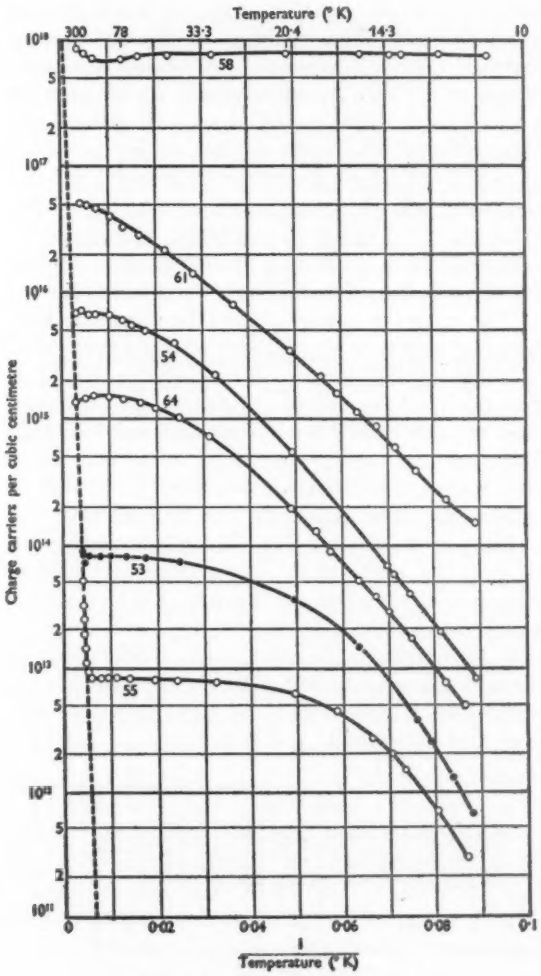

FIGURE 2 – *Variation of N with 1/T.*

The electron-wind is blowing from left to right along the ribbon with a drift-speed v which is μE: here E stands for the electric field-strength. Now, an electron which is moving with speed v at right angles to a magnetic field of strength H suffers a force evH/c at right angles to both the direction of the field and the direction of motion of the electron. Here c stands for a factor which is determined by the units that are used; if classical units are used, c is equal to the speed of light in a vacuum. In this instance, the direction determined by this rule is in the plane of the paper, and the sense of the force is upward. The electrons are urged towards the top edge of the ribbon, and there they tend to pile up. As they pile up, the top edge of the ribbon becomes more negative than the bottom edge, and this goes on until the upward magnetic force on an electron is just compensated by an equal downward electric force. The horizontal electric field is exerting a rightward force eE on the electron; and taking this also into account, we see that the electrons experience a resultant electric force which is tilted at an angle θ clockwise from the horizontal. This is also the angle of tilt of the equipotential line. Its tangent is given by the equation:

$$\tan\theta = (evH/c)/eE = (e\mu EH/c)/eE = \mu H/c. \quad (1)$$

This is the fundamental formula of the Hall effect, giving the mobility of the electron-gas in terms of measurable things.

Since a semiconductor has been defined as a substance in which N, the number of electrons per unit volume, varies with the temperature, let us turn away from mobility for the moment, and see how the Hall effect determines N.

The current-density i in the wire is the product of the wind-speed, which is μE, by the number of electrons per unit volume, which is N, by the charge of the individual electron, which is e. This amounts to $Ne\mu E$, and thus for μ we have the expression i/NeE. Substituting this into (1), we find:

$$N = iH/ecE \tan\theta \quad \ldots\ldots\ldots\ldots (2)$$

This is another form of the basic equation of the Hall effect.

The values of N leading to the curves in figure 2 were found in this way. There is much to be learned from these curves. Before beginning to decipher them, the reader must note that the abscissa is not absolute temperature T but its reciprocal $1/T$, so that the left-hand side is the hot side. Further, the ordinate is strictly log N. However, the values of N are printed along the vertical

axis and the values of T along the top of the diagram.

These curves correspond to samples of germanium—now the most famous of semiconductors—with various admixtures of arsenic: sample No. 55 was the purest and No. 58 the most impure. Here we are able to see the origin of the long-prevailing notion that semiconductors conduct only because of the presence of impurities. On the cool side of the diagram the presence of impurities clearly has an immense effect. On the hot side, however, all the curves merge into one. It is reasonably believed that, as indicated particularly by curves 53 and 55, all the curves become part of the nearly vertical line, and that this is the curve that would be displayed by an ideally pure sample of germanium. Such a sample would be called an intrinsic semiconductor, and in general this term is applied to semiconductors in the intrinsic range of temperatures, which is that where the various curves have merged.

On the cool side, most of the curves rise with rising temperatures. This means that some of the electrons which at low temperatures are bound to atoms are set free by heat. Clearly the atoms to which these detachable electrons are bound must be atoms of impurity—arsenic atoms in this case. From these curves it is possible to estimate how much energy it takes to loosen a detachable electron from an impurity-atom; the values are generally of the order of a few hundredths of an electron-volt. Two of the curves present apparent exceptions. The curve for sample No. 58 is flat. This was the sample with the greatest concentration of impurity-atoms, and its flatness means that when the impurity-atoms are close together the work of detachment falls to so low a value that all of their detachable electrons are already freed even at 11° K. The curve for sample No. 58 slopes in the wrong sense near 300° K, which suggests that here electrons are losing their freedom as the temperature goes up. However, what this really means is that formula (2) is oversimplified and is giving incorrect values for N in this region.

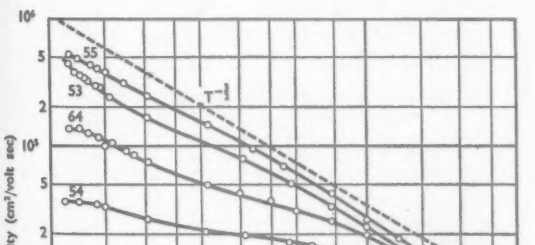

FIGURE 3 – *Variation of mobility with temperature.*

From the curve in the intrinsic range it is possible to estimate how much energy it takes to loosen an electron bound into the texture of germanium, pure or impure. This is about 0·75 electron-volt. The corresponding value for silicon is about 1·10 electron-volt. These values vary with the temperature.

It has already been said that under the influence of an electric field, E, the electron-gas becomes an electron-wind. The wind-speed is μE; the coefficient μ is by definition the mobility. Except under extreme conditions, μ is independent of E, because the free electrons are exposed to two agents that counteract each other. One of these is the field E, which accelerates the electrons up the field-direction. The term 'forward speed' may be used for the speed up the field-direction. A free electron gains forward speed from the field, and thus also gains kinetic energy. But every now and then it collides with something that takes away the forward speed and the kinetic energy that it gained since its previous collision.

These obstacles that lie in the electron's path were formerly supposed to be the atoms. This is so natural a supposition that one can scarcely imagine it to be wrong, yet it has led to conclusions that do not agree with experiment. The present hypothesis is better expressible in mathematics than in words, but may be crudely translated into words as follows: the obstacles which the electrons encounter are the elastic waves maintained by thermal agitation in the solid. This theory leads to the conclusion that the mobility should vary inversely as the 3/2-power of the temperature. This $T^{-3/2}$ law is exhibited by the dashed line in figure 3, where the abscissa is log T but the values marked are those of T. The curves correspond to the same samples of arsenic-containing germanium as supplied the data for figure 2. One sees that the purer the sample, the more nearly the data conform to the $T^{-3/2}$ law. It may be reasonably conjectured that in ideally pure germanium the mobility is determined by the thermal agitation of the solid—or of the lattice, as many people say. For the benefit of those who may wish to refer to the literature, it may be mentioned that this mechanism is known as lattice-scattering.

The curves of figure 3 also show that the presence of impurities introduces a factor that reduces the mobility, and reduces it the more effectively the greater the amount of the impurity and the lower the temperature. This further factor is the electrical charge of the impurity-atoms; such of these as have contributed to the host of free electrons are of course positively charged by reason of their loss. Such atoms deflect the electrons that approach them, and thus act as extra obstacles to the electron-wind. It is interesting to note that the mathematical theory is the same as that which Rutherford applied to the deflections of alpha-particles by atomic nuclei.

Though this article is not about metals, attention must be drawn to one of the contrasts between metals and semiconductors. In pure elementary metals, the mobility is determined by lattice-scattering; yet the mobility is usually more nearly proportional to T^{-1} than to $T^{-3/2}$. The difference arises from the fact that in metals the number of free electrons per unit volume is usually much greater than in semiconductors. Electrons so densely assembled do not conform to the familiar Maxwell-Boltzmann distribution, which is one of the stipulations required for the $T^{-3/2}$ law. In semiconductors the electron-gas is usually so rarefied that the Maxwell-Boltzmann distribution prevails, though it would be an exaggeration to say that this is always so.

Taking the expression $eN\mu E$ which was derived for the current-density i, and dividing it by E, we are left with what is by definition the conductivity of the substance, usually denoted by σ:

$$\sigma = eN\mu \quad \ldots\ldots\ldots\ldots\ldots (3)$$

Now we see that σ may conceivably go either up or down with rising temperature: up if the rise in N overpowers the fall in μ or if μ itself is rising, down if N is constant or if the fall in μ overpowers the rise in N. These possibilities are illustrated by the family of curves in figure 4, relating to the same set of samples of germanium contaminated with arsenic. Here $1/T$ is the abscissa, so that the cool side of the diagram is the right side; log σ is the ordinate.

At low temperatures, conductivity is seen to rise with temperature: this is the behaviour that used to be considered distinctive of semiconductors. At intermediate temperatures, for all but the impurest sample, σ falls with rising temperature; this is the behaviour that used to be thought distinctive of metals, but we see that semiconductors also may share it. At high temperatures the samples are in the intrinsic range, where impurities no longer matter because the free electrons that they provide are small in number compared with those that are detached from the germanium itself.

The most sensational feature of the Hall effect has not yet been mentioned. It was said that under the circumstances depicted in figure 1—magnetic field pointing through the plane of the paper towards the onlooker—the equipotential line is tilted clockwise by the magnetic field. This is true of germanium contaminated with arsenic; it is also true of many other semiconductors and of many metals. There are, however, both semiconductors and metals for which the tilt is counter-clockwise. Sensational is the right word here, for the fact implies that in these substances there is not a drifting gas of ordinary negative electrons, but a drifting gas of positive electrons. Yet, in spite of this, physicists in general do not believe that positive electrons exist in metals or in semiconductors.

Years ago there was a German book entitled 'The Philosophy of the As If.' The Hall effect might have provided a fine example for the author,

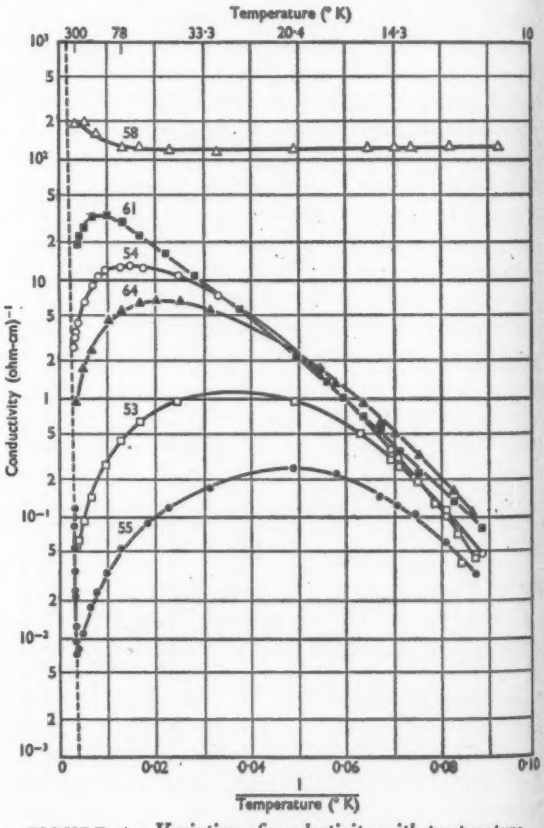

FIGURE 4 – *Variation of conductivity with temperature.*

since physicists believe that in the substances in question negative electrons are behaving as if they were positive electrons. This statement, however, must be more carefully expressed.

What have been called the bound electrons of such a substance as pure germanium are distributed into groups, or, technically, bands. In germanium there is a group—the only one that we shall consider—which is specifically called the valence-band. At absolute zero it is presumed that the valence-band would be a filled band. What this means in theory would be hard to explain in a reasonable space; what it means in practice is that the electrons of the band do not take part in conduction. At absolute zero, could we reach it, we should presumably find that germanium is an insulator.

It is, however, possible, by heat or by any of various artifices, to prise electrons out of a filled band. Let us suppose that the valence-band is short, by say x electrons, of the number required to fill it. In this situation, quantum theory leads to a most remarkable conclusion. It is that the group or band of electrons from which x electrons are missing behaves like a gas composed of x mobile positive electrons. We describe this state of affairs by saying that the semiconductor is pervaded by a gas of 'holes.' By this usage we avoid the undesired implications of such a term as positive electrons, and we give at least a hint of the theoretical basis.

The commonest artifice for creating holes—for depopulating the valence-band, one might say—consists in mixing the germanium with an impurity of an appropriate kind. Arsenic, the impurity to which the illustrations given here have hitherto referred, is definitely not of an appropriate kind. Atoms of boron or of gallium will serve. Such atoms attract and capture electrons. They take electrons from the valence-band, and leave the holes behind. A semiconductor of such a character is called a *p*-type semiconductor. Germanium mixed with arsenic, or any similar substance mixed with impurity-atoms which readily give up electrons, may be called an *n*-type semiconductor. Impurity-atoms which readily lose electrons may be called donor atoms or simply donors, and impurity-atoms which capture electrons out of the valence-band acceptor atoms or acceptors.

The electrons captured by acceptors are immobilized. Conduction is left to the holes; the current is the hole-gas blowing like a wind through the semiconductor. The Hall experiment may be performed; the concentration N—better now called P—of holes and the mobility μ_p of holes may be estimated by the formulae that have already been given; these, and the conductivity σ, may be plotted against the temperature, or their logarithms against $1/T$.

When plots such as these are made, they look remarkably like those of the illustrations that refer to electron-gas in germanium mingled with arsenic. The concentration P of holes rises with rising temperature, and tends to a limit. This shows that it takes work for an acceptor to prise an electron out of the valence-band. Analysis of the curves shows that the work is of the order of a few hundredths of an electron-volt, and depends on the value of P. Mobility is influenced jointly by lattice-scattering, predominant at high temperatures, and by impurity-scattering, conspicuous at low. Conductivity usually rises with rising temperatures to a maximum, then declines until the intrinsic range is reached. The analogy with electron-gas is far-reaching, and yet not perfect—another reason for avoiding such a term as positive electrons when talking about holes. The mobility of holes may be considerably less than that of electrons, say half as great. In this respect the holes behave as though they were more massive than electrons. Quantum theory indicates that, in the interior of a solid, even electrons may behave as though their mass were different from the value familiar to us in electron-beams crossing a vacuum.

Turning back to the intrinsic semiconductors, it has up to now been implied that, in the intrinsic range, electrons are loosened by heat from the texture of the germanium, and that is all. But it is not all, for the electrons in question are taken from the valence-band, and holes are left behind. In the semiconductor in the intrinsic range, there are both an electron-gas and a hole-gas. When an electric field is applied, they drift in opposite directions with unequal drift-speeds. The Hall experiment may be performed, but now the simple formulae used in this article must be replaced by others not quoted here. They involve, of course, the concentrations and the mobilities of both the electrons and the holes. In figures 2 and 4 the points which are plotted along the intrinsic part of the curves were derived from the data by the use of these formulae.

Interesting things can be observed when a limited number of holes is, so to speak, injected into an *n*-type semiconductor. This may be done by pressing a pointed electrode of metal against a rod of semiconductor, making it positive with respect to

the rod, and applying a voltage of appropriate sign for a limited time. Electrons are drawn out of the rod; a flock of holes is left behind; and, if there is an electric field, the flock drifts along the rod, gradually broadening and becoming vaguer in outline as it goes along, but still not losing its identity. When the flock passes another point-electrode which is negative with respect to the rod, there is an inrush of electrons through the point-electrode: by this means the advent of the flock is detected. The drift-speed of the flock may be measured by timing its departure from the first point-electrode and its arrival at the second. This drift-speed is sometimes found equal to the drift-speed computed from the Hall effect, and sometimes not. In the latter case, the discrepancy may be ascribed to oversimplification of the formulae. It should be mentioned here that a similar effect is observed when electrons are injected into a *p*-type semiconductor, and that the conjunction of an *n*-type semiconductor and a *p*-type semiconductor makes an excellent rectifier.

One would like to know a general rule for determining which impurities—perhaps a broader word, like anomalies, would be more fitting—produce an *n*-type semiconductor and which a *p*-type. While this is in general yet to be achieved, some progress has been made. Take, for instance, arsenic in germanium. The arsenic atom has one more electron than the germanium atom. It is very plausible to suppose that when an atom of arsenic crowds itself into a site in the lattice which would normally be occupied by a germanium atom, the extra electron becomes a sort of fifth wheel which finds no place to fit itself into, and goes rolling off through the substance as a free electron. The simile of the fifth wheel is more apt than it appears to be at first. The outermost electrons of a germanium atom number four, and in pure germanium they dispose themselves in a tetrahedral arrangement which links up with the identical arrangements of the neighbouring atoms; there is no place for a fifth electron in such a texture. Now take gallium in germanium. The gallium atom has one fewer electron than the germanium atom. Its outermost electrons number three. One may imagine that when a gallium atom has been forced into a site in the lattice which would normally be occupied by a germanium atom, there is a hole where the fourth electron ought to be, and this hole goes roaming through the substance. This is just an analogy, however, and like other analogies it may serve as an aid to memory but must not be pressed too far.

Acknowledgment. The author wishes to express his thanks to Bell Telephone Laboratories Incorporated, New York, for permission to publish this article.

Book reviews

HIGH-ENERGY PARTICLES

High-energy Particles, *by Bruno Rossi. Pp. xii + 569, with half-tone and line illustrations. Constable and Company, London.* 1953. 65*s. net.*

The appearance of a book on high-energy particles by a distinguished contributor to this branch of physics will be welcomed by the increasing number of physicists preoccupied with the subject. Until 1945, high-energy particles were the exclusive interest of the cosmic ray physicists; it is certainly time that the convergence of the interests of these investigators with those of workers using artificially accelerated particles was strengthened by the publication of a book covering both methods of studying nuclear interactions.

High-energy particles are defined as those whose energy exceeds the binding energy of nuclear particles. The book presents a comprehensive account of our knowledge of these particles up to the end of 1951. The treatment combines an historical with a logical development of the subject. A detailed account of the theory of the electromagnetic interactions of the particles is followed by a short description of the experimental methods employed. The properties of the elementary particles are then discussed more fully, and the following chapter deals with the theory of cascade showers in considerable detail. A shorter chapter correlates the experimental with the theoretical data on electromagnetic interactions. The two remaining chapters, comprising about one-third of the book, are devoted to the data on nuclear interactions obtained from experiments with artificially accelerated particles and from cosmic ray studies. In the present state of the subject it is not surprising that the last chapter is the longest in the book. It includes a well chosen and very beautiful collection of 16 microphotographs from photographic plate experiments, and 14 cloud-chamber pictures. There are four short mathematical appendixes, and two dealing with units and the standard atmosphere. The bibliography tabulates nearly 500 references.

The approach is predominantly experimental; meson theory is deliberately avoided. Since much of the material found in this book has not appeared outside the original literature, a handbook of this kind was urgently needed. It should help to prevent further differences arising in the nomenclature adopted by accelerator and cosmic ray physicists.

In such a rapidly developing subject one would expect that several important observations would be made even while a book upon it was passing

through the press. This has indeed happened, especially amongst the groups using the new high-energy accelerators, but the intuitive feeling of the author for the most fruitful trends of investigation will greatly prolong the useful life of the book. The production is good, and the very many graphs, diagrams, and tables are clearly and accurately reproduced.

A. G. MADDOCK

STUDY OF TIMBER

Timber: its Structure and Properties, *by H. E. Desch. Third edition, revised. Pp. xxiv* + 350. *Macmillan and Company Limited, London.* 1933. 25*s. net.*

The first edition of this book was published in 1938, and quickly established itself as a clear and reliable introduction to the study of timber. For the present edition the general framework of the text has been preserved but brought up to date, and several new illustrations have been added: there are now 65 plates and 46 line drawings. The sections on the classification of trees and the nomenclature of timbers have been rewritten, as has also the chapter on defects in timber. Dr Desch feels that the seriousness of the problem of fungal and insect damage to timber has been exaggerated: he says that much of this damage could be avoided were simple basic facts more widely understood and proper maintenance observed. There are three appendixes, one of which is a useful list of the commoner hardwood tree genera, with the families to which they belong. The book also contains a selected bibliography and a subject index, which add to its usefulness. As a concise account of the structure and properties of timber it should continue to render good service to all those concerned directly or indirectly with wood technology.

EDIBLE ITALIAN SEA ANIMALS

Gli animali comestibili dei mari d'Italia, *by Arturo Palombi and Mario Santarelli. Pp. viii* + 349. *Ulrico Hoepli, Milan.* 1953. *Lire* 3800 *net.*

This is a well produced book, on art paper, with a very large number of illustrations, mostly in half-tone, and two coloured plates figuring four species of prawns. The work is a catalogue of the edible marine animals of Italian waters, including the fishes, tunicates, echinoderms, molluscs, and crustacea. The general plan is for each of the species treated to have a page to itself, with an excellent figure which is calculated to make recognition as easy as possible, accompanied by a short description, a note on the economic value, and one on habitat and fishery. This is followed by a list of the animal's local names, including not only those which it bears in various parts of Italy but those used in a number of other countries. The description refers to its form, colour, and size. It is interesting to note that four sea urchins (*Paracentrotus lividus, Sphaerechinus granularis, Psammechinus microtuberculatus,* and *Arbacia aequituberculata*) are used as food, and that among the other invertebrates so employed are various cephalopods as well as gastropods (including limpets, *Haliotis,* and snails) and bivalves, and also crustacea (prawns, shrimps, lobsters, crabs, and *Squilla*). The authors are to be congratulated on the production of a very useful introductory handbook to this subject.

T. A. STEPHENSON

MUSHROOMS AND TOADSTOOLS

Mushrooms and Toadstools, *by John Ramsbottom. Pp.* 46, *with* 70 *plates. Collins, London.* 1953. 30*s. net.*

The ingredients for the rich and varied fare in this volume of the 'New Naturalist' series have been gathered in Dr Ramsbottom's half-century of forays in the field, the library, and the herbarium. In his treatment of the biology of the larger fungi, a discussion of their growth-requirements is used to throw light on their seasonal appearance, the section on spore characters introduces the principles of classification, and a description of sclerotial structure leads up to an account of ergot and *Cordyceps.*

In the chapters on fungus ecology, the brevity of the text severely limits the section on grasslands, marshes, and sand-dunes, but has largely spared the account of the woodland fungi. Apart from the lists provided in these sections, the book gives no systematic account of the agarics, but includes chapters dealing specifically with puffballs and earthstars, stinkhorns and phalloids, bird's-nest fungi, and truffles.

The distinctive character of the work appears most clearly in the chapters on edible and poisonous fungi, mushroom cultivation, dry rot, truffle-hunting, fairy rings, and the history of mycology. Here the facts are interwoven with the diversity of fables brought to light by the author's inspired rummaging in the byways of literature and folklore.

A final chapter is included on the utilization of micro-fungi in industrial fermentations and the production of penicillin.

The coloured photographs show little connection with the text, but the majority achieve verisimilitude and all are decorative.

R. W. MARSH

ESSAYS OF JEAN REY

The Essays of Jean Rey, *a facsimile reprint of the original edition of* 1630, *with an introduction by Douglas McKie. Pp. xliv* + 144 + *xlv–lxxxiii. Edward Arnold and Company, London.* 1951. 21*s. net.*

The Rey family were small landowners in the Dordogne, and Jean, author of the celebrated 'Essays,' graduated in medicine at the university of Montpellier in 1609. The exact date of his birth is unknown, but is supposed to have been about 1582 or 1583; he died about 1645. Though he acquired a considerable reputation as a physician, his claim to remembrance lies in his views on combustion expressed in the essays here reproduced in facsimile from the British Museum copy of the original edition, 1630; copies of this edition are now very rare, apparently only seven being extant. Rey believed that the source of the increase in weight which metals undergo when calcined must be sought in the air, 'which in the vessel has been rendered denser, heavier, and in some measure adhesive, by the long-continued heat of the furnace: which air mixes with the calx (frequent agitation aiding) and becomes attached to its most minute particles.' He was thus approaching the right track, though it was left to Lavoisier to set foot firmly upon it.

In an appendix to the book Dr McKie gives the text of letters passing between Mersenne and Rey, and Mersenne and Brun; these are of much interest. The publishers are to be thanked for their public spirit in making this facsimile volume available; it may be remembered that several years ago they performed a similar service in publishing a facsimile reprint of Thomas Norton's 'Ordinall of Alchimy.'

E. J. HOLMYARD

RECENT BIOLOGICAL HISTORY

A Hundred Years of Biology, *by Ben Dawes. Pp.* 429. *Gerald Duckworth and Company Limited, London.* 1952. 30*s. net.*

All who have written the history of a science have found their difficulties increase as they advance toward the contemporary scene, at which the method

and nomenclature of the science become familiar. The reason for this apparent contradiction is simple. Up to a point—commonly about the limit of living memory—the historian can afford to neglect all but the main line of development, but on reaching the more familiar modern period he is in the dark as to which will prove to be the main line and so has to discuss all. Thus Dr Dawes has set himself a most formidable task. He has attacked it with great courage and has produced a very useful volume. Nevertheless most of his chapters show the dichotomy suggested above—into an earlier period treated historically, and a later that is almost like a dictionary in form. This is in no way a reflection on the learning or literary skill of the author; it is inherent in the subject. He has, in fact, produced a most useful reference book which biologists of all types will find to fill a serious gap in the literature. The book is equipped with an effective bibliography and an admirable index of both subjects and names. Of the nineteen chapters the most readable are perhaps those on marine biology and on parasites, probably because these are the most susceptible of historical treatment in the proper sense. This does not imply that the less readable are less useful. Indeed, we recognize that precisely the opposite may well be the case, and that the book may develop into an increasingly valuable reference work.

CHARLES SINGER

ANIMAL LOCOMOTION

How Animals Move, *by James Gray. Pp.* 114. *University Press, Cambridge.* 1953. 16*s. net.*

This book is based upon the series of lectures for children and others given by Professor Gray at the Royal Institution in the winter of 1951–2. It summarizes all the work on animal locomotion that has been done during the last thirty years, mainly under the inspiration of Gray and as the outcome of his pioneer researches. The book starts with certain simple laws of mechanics, laws that apply to all movement whether living or not, and shows how evolution may account for the development of increasingly efficient organs of locomotion, fins becoming limbs and limbs becoming wings. Examples to illustrate the argument are drawn from all divisions of the animal kingdom, from the amoeba to man; the sections dealing with swimming and the creeping of serpents, subjects on which the author has himself done so much work, are particularly interesting. Explanations are also given of some of the latest researches that have been reported, such as those on the flight of diptera, and on the electric fields that exist round the bodies of certain fish.

Professor Gray has a fascinating story to tell, and he tells it with consummate skill: his writing is simple and direct, and he clarifies complex matters so that all may understand. He unfolds his argument from point to point in a way that is delightful to follow. The drawings, though some of them are rather crude, adequately illustrate the text, and the plates present a splendid series of dramatic action-photographs.

L. HARRISON MATTHEWS

AETHER AND ELECTRICITY

History of the Theories of Aether and Electricity: The Modern Theories, 1900–1926, *by Sir Edmund Whittaker. Pp. xi* + 319. *Thomas Nelson and Sons Limited, London.* 1953. 32*s.* 6*d. net.*

The first volume of this work, which was concerned with the classical theories, was reviewed in ENDEAVOUR in January 1952. Sir Edmund Whittaker then promised a second volume dealing with the modern theories and continuing the story to the present time. The wealth of material and the many new developments in physical theories during the past fifty years have been too considerable for a single volume. The second volume continues the story to the year 1926, and a third volume, dealing with the period from 1926 to 1950, is now foreshadowed.

During, and shortly before, the first quarter of this century there was a great ferment in physical ideas. On the experimental side there were, for instance, the discovery of radioactivity, of the electron and proton, of isotopes, of the structure of the atom, of the diffraction of X-rays by crystals, of photo-electricity, of electron diffraction, and the analysis of series in spectra. On the theoretical side there were the developments of special relativity, quantum mechanics, general relativity, matrix mechanics, and wave mechanics. The aether recedes into the background.

To give an account of this revolution in physics, dealing with experiment and theory and the interaction of each on the other, has been a Herculean task. Sir Edmund Whittaker has woven these developments into a connected story with sound judgment and balanced perspective. The principal investigations are summarized in sufficient detail for the reader to follow the train of ideas. The history is fully documented with references to the original papers. No paper of first importance appears to have escaped notice; the amount of reading entailed must have been colossal.

This great work is a mine of information and invaluable for reference. In congratulating Sir Edmund Whittaker, who is now in his 81st year, on the completion of this volume, we may express the hope that he will be able to complete his plans with the publication of a third volume bringing the story up to 1950.

H. SPENCER JONES

KOSMOS LEXIKON

Kosmos Lexikon der Naturwissenschaften, A–K. *Pp.* 1591. *Kosmos Gesellschaft der Naturfreunde; Franckh' sche Verlagshandlung, Stuttgart.* 1953. *Halflinen, DM* 29.50; *half-leather, DM* 36 *net.*

The growing extent to which science is today penetrating into everyday life has created a demand for books and dictionaries which will enable the general public interested in science to obtain information about scientific terms as mentioned in newspaper reports, radio and television talks, and general lectures. This demand seems to be most competently met by the Kosmos Society's 'Dictionary of the Sciences, with special regard to the Biological Sciences.' A list of 20 000 definitions has been compiled by a team of specialists, most of them university teachers; they are given in alphabetical order, and the present volume contains A–K.

The list consists of terms used in the various branches of science, the particular branch being represented by a symbol placed after each term, and of the names of prominent scientists, past and present, from all countries, accompanied by short biographies and an indication of their main field of work. Definitions are given in simple language which will be easily understood by a general reader, and the text is illustrated by clearly labelled diagrams and good coloured plates. So far as checked, the list is amazingly comprehensive; cross-references are added where necessary, and reference books are mentioned for those requiring more detailed information.

The dictionary will be a useful addition to reference and other libraries, and will serve as a reliable guide

through the ever-growing complexity of modern scientific terminology.

G. SCHLESINGER

HISTORY OF VERTEBRATES

Geschichte der Wirbeltiere, *by Emil Kuhn-Schnyder. Pp.* 156. *Benno Schwabe Verlag, Basle.* 1953. *Swiss fr.* 14 *net.*

This little volume, hardly more than a long pamphlet, is on the evolutionary history of the vertebrates. It is based primarily on popular lectures given in the winter of 1949–50 to the Zürich *Volkshochschule*, and published in its journal as a series of ten articles. These were revised and printed as a volume in 1951 and are now enlarged and again revised and provided with further notes. As it stands, the work has three excellences, all peculiarly hard to attain. First, it is clearly and simply written and beautifully illustrated—largely by J. Mayer-Gräter, who died in 1952. Secondly, it hits off happily a standard that should be intelligible to the layman and, combined with the notes, is also helpful as a palaeontological basis for the student of comparative anatomy. Thirdly, it is skilfully equipped with bio-bibliographical notes on the founders of palaeontology, from Cuvier and William Smith to Broom and Weidenreich, as their names arise in the text. This method of introducing historical material into scientific narrative is a happy idea, worth extension to other sciences. Perhaps the best, and best illustrated, section is that which deals with the difficult subject of the invasion of the land and the passage from fish to amphibian.

CHARLES SINGER

PORTRAIT OF LIEBIG

Justus von Liebig in eigenen Zeugnissen und solchen seiner Zeitgenossen, *by Hertha von Dechend. Pp.* 141, *with three plates. Verlag Chemie, Weinheim.* 1953. *DM* 8.40 *net.*

The Liebig Museum Society in Giessen has produced this attractive book; the author, and the writer of the appreciative but discriminating introduction, Professor Hartner, are members of the *Institut für Geschichte der Naturwissenschaften* at Frankfurt-am-Main. The first four pages consist of extracts from Liebig's autobiography, the last thirty-three contain a most useful list of his publications, various notes which amplify the text, brief details regarding his contemporaries, and a Liebig bibliography. The remainder of the work consists of well chosen extracts from Liebig's own letters and those of his scientific colleagues, especially on the personal side, arranged chronologically on the left and right hand pages respectively. This rather condensed and disjointed presentation of the subject matter does not detract from its interest.

Liebig wrote to Wöhler 'I am attached to you with my whole soul; our friendship warms my life. I have always been sorry that you should waste your time in work which is unworthy of you'—and then the words which still ring true after more than 120 years—'throw your writing to the devil and go into the laboratory, where you belong.' Wöhler replied 'Berlin is not Giessen. What you can buy for six batzen costs a thaler here. Otherwise all lectures and all translation work could go to the devil.'

Liebig told his students: 'Don't take notes in my lectures; watch my experiments and think about them at home.' The controversy between Pasteur and Liebig is not mentioned, though criticisms by other colleagues are not excluded, and Liebig's friendship with Faraday is revealed in a pleasing manner. His incarceration in the university gaol at Erlangen for rowdy behaviour and for knocking a policeman's helmet off, and his hurried departure from Bavaria owing to political activities, throw an interesting light on his student days in 1822.

A stimulating feature of the book is the genealogical tree showing how the work and teaching of Liebig reached many of the great chemists of different countries.

F. CHALLENGER

WAVE MECHANICS

Elements of Wave Mechanics, *by N. F. Mott. Pp.* 156. *Cambridge University Press, London.* 1952. 21*s. net.*

In the preface, this book is described as being 'written to replace the author's "An Outline of Wave Mechanics," published by the Cambridge University Press in 1930, and now out of print. It is intended for students in the final year of an honours course of experimental physics, and also as an introduction to more advanced text books . . .' For the reviewer, the present book satisfies only the second of these intentions. It cannot be regarded as replacing the original volume of 1930, which was an outstanding work, of great value not only to students of physics but to many others who were trying to understand the ideas of wave mechanics. It was written in such a way that most of the ideas were readily intelligible to the reader whose mathematical knowledge was slender. The present book is more concentrated and more concerned with mathematical detail, and in many places the ideas have to be extracted from the equations in a way which will make the book appeal to a much more restricted circle of readers. Many will feel that this change in the nature of the book is unfortunate, and will hope that the publishers and author will either bring the original book up to date, or will reprint the present volume with the addition of more explanatory text of the kind which the author can write so beautifully. In its present form the book should be of great value to the student of physics, and the exercises at the end of some sections will enable him to see how much he has really understood. It is perhaps unfortunate that the author should write the relation $W = h\nu$ with no mention of the mass energy, since although what is written is perfectly correct, it creates an apparent difference from other books, which may well puzzle the more elementary reader. As an introduction to more advanced text books the book needs a preliminary chapter explaining how wave mechanics came into being. Provided the reader can obtain this from lectures or some other source, the present book will be valuable as a guide to more advanced works, and many will find it useful for reference.

W. HUME-ROTHERY

ELECTROENCEPHALOGRAPHY

The Living Brain, *by W. Grey Walter. Pp.* $x + 216$. *Gerald Duckworth and Company Limited, London.* 1953. 15*s. net.*

This book is described as the first attempt to record for the general public the modern work on brain function. The actual scope is much more restricted, for it is almost entirely devoted to an attempt to correlate records of the electrical activity of the brain (the electroencephalogram) with human behaviour. The author has made notable contributions in this field, he has a sound neurophysiological background, and he is also the acknowledged leader in England in the techniques of electroencephalography. Yet one remains sceptical at the end of long chapters characterized by lively description and vivid imagery. A besetting failing of electroencephalographers is that they are so fascinated by their

tracings of electrical potentials ('brain waves') that they almost ignore the problem: how does activity in the ten thousand million individual nerve cells of the brain give rise to these potentials remotely recorded from the surface of the scalp? Electroencephalography remains thus an empirical science, and attempts are made to correlate the different kinds of brain waves with performance of the brain as a whole, or even with performance of the individual person. Such attempts would carry much more conviction if they were associated with a severely critical appraisal of the relevant data. But Dr Grey Walter is an enthusiast who is carried away by his ideas, and would have us believe that it is possible to classify human beings into distinct psychological types on the basis of a few seconds of electroencephalographic tracings. The final conclusion is that 'Enough is known today about the living brain to reduce material waste and human misery—in education, in correction, and in the development of mature personal relations.'

The best way to enjoy this book is to become infected with the zest of the author and be carried away by his enthusiasm. The ingenious models, particularly the 'tortoise,' then cease to irritate. They are obviously sources of delight and joy to their fond parents, and we can share these emotions and marvel at the conceptional ingenuity without deluding ourselves that they have scientific significance. Except for some detailed descriptive accounts of 'brain waves' the book is eminently readable. It is assured of a wide appeal, not only to philosophers and psychologists, but to those of the general public who like to read of the marvels of modern science. J. G. ECCLES

ORIGIN OF LIFE

The Origin of Life, *by A. I. Oparin, translated by Sergius Morgulis. Pp.* 270, *with line diagrams. Dover Publications Inc., New York.* 1953. *Cloth,* $3.00; *paper,* $1.70 *net.*

The interest that has been taken in recent years in the origin of life is second only to that taken in space navigation and is related to it, both because it represents a similar adventure into the recesses of time, and because of the realization that if life on this planet is not unique and we may expect to find other forms of life in other worlds, we ought first to get some idea of how life originated on this one. The new interest is not like the old, the establishment of the shocking idea that life might not have been created but that it just grew. Most scientists are prepared to accept that: what they and the public now want to have is a more precise idea of how it happened. For this, nothing that has yet appeared is better than Oparin's 'Origin of Life,' of which a popular edition has just been published, with a new introduction by Professor Morgulis. This is all the more welcome inasmuch as the earlier edition is almost unobtainable.

Although it has not been able to include any of Oparin's most recent contributions, which amplify and deepen his original ideas, the book has stood the test of time well, and its central thesis is unshaken. This is that life on the Earth arose out of the interaction of light with the gases methane, ammonia, and carbon dioxide, which would form the natural atmosphere of a primitive planet. Indeed, in one respect it has received a remarkable confirmation, for Urey and Miller have been able to make several amino acids, the characteristic components of the proteins, by electrical excitation of such a mixture of gases. Professor Morgulis has added other expansions and confirmations, notably on the importance of protein enzymes. In one respect I fear he would not find Oparin in agreement with him, that is when he seeks to equate the virus with the gene and to imply that life originated from chance variations operating on a concentration of complex substances. In Oparin's view the processes and substances of life form and have always formed an indissoluble whole.

Oparin's conclusions can be summed up in his own words, taken from his article in the Soviet Encyclopaedia[1]: 'Life is a particular form of movement of matter which appeared at a certain stage of its historic development and is represented at the present moment on our planet by an enormous number of individual systems—the organisms.'

J. D. BERNAL

ADSORPTION

The Dynamical Character of Adsorption, *by J. H. de Boer. Pp. xv* + 239. *Oxford University Press, London.* 1953. 30*s. net.*

De Boer has examined the phenomenon of adsorption in terms of the dynamic character of molecules, their number, speed, direction of motion, time of lingering at surfaces. For those who have difficulty with molecular magnitudes and numbers per cc, he provides a magnified picture in which the molecules are blown up to the size of bees and a square centimetre becomes a 200-mile square erected on a baseline from Hastings to Torquay. Each phenomenon is illustrated with reference to this 'gas of super bees.' The writing is fluid and dynamic but never surrenders the accuracy essential to a scientific text which is designed to provide the student with the fundamentals of the subject and the advanced worker in the field with much to meditate upon concerning unsolved problems. It deals mainly with adsorption due to physical interactions between surfaces and fluids, only slightly with chemisorption. It provided both pleasure and instruction to one who has spent many moons in study of the phenomenon. HUGH TAYLOR

[1] French translation in *Questions Scientifiques*, II. Paris. 1953.

POLLEN OF MONOCOTYLEDONS

New Zealand Pollen Studies: The Monocotyledons, a Comparative Account, *by Lucy M. Cranwell. Bulletin of the Auckland Institute and Museum, No.* 3. *Pp.* 91. *Harvard University Press, Cambridge, Mass.; Auckland Institute and Museum, Auckland, N.Z.* 1953. *Cloth,* 30*s*; *paper,* 20*s. net.*

Miss Lucy Cranwell (Mrs Watson Smith published the first of her 'New Zealand Pollen Studies' (in key form) in 1942. The present work, on a much larger scale, is a systematic account of the pollen grains of the monocotyledonous plants of New Zealand. All the 17 relevant families are treated in proportion to their palynological interest and importance, the lily, sedge, and orchid families therefore being dealt with at greater length than the remainder. The account of each family is prefaced by a *résumé* of previous work from the time of Grew and Malpighi onwards. Descriptions of the various species follow: these, read in conjunction with the many excellent photographs, should greatly facilitate the task of future pollen analysts. The work also includes a glossary (very necessary, the terminology of pollen morphology being in the fluid condition that it is), keys to pollen determination, a synoptic table of pollen characters, a bibliography of 247 items, and an index.

Mrs Watson Smith's monograph is an outstanding contribution to a growing subject. H. A. HYDE

Some books received

(*Note.* Mention of a book on this page does not preclude subsequent review.)

BIOCHEMISTRY

Antibiotics, *by F. A. Robinson. Pp.* 132. *Sir Isaac Pitman and Sons Limited, London.* 1953. 15*s. net.*

BIOLOGY

Biologie der Zelle, *by Erich Ries, edited by Manfred Gersch. Pp.* 552. *B. G. Teubner Verlagsgesellschaft, Leipzig.* 1953. *DM* 24.40 *net.*

Symposia of the 6th International Congress of Microbiology, *in six volumes: Bacterial Cytology; Growth Inhibition and Chemotherapy; Nutrition and Growth Factors; Microbial Metabolism; Interaction of Viruses and Cells;* Actinomycetales, *Morphology, Biology and Systematics. Fondazione Emanuele Paterno, Rome.* 1953. *Lire* 2000, 1000, 1400, 1000, 1300, *and* 1600 *respectively.*

Tissue Culture, *by E. N. Willmer. Pp.* 175. *Methuen and Company Limited, London.* 1953. 9*s.* 6*d. net.*

BOTANY

The Hidden Life of Flowers, *with photographs by R. H. Noailles. Translated from the French text of J. M. Guilcher. Pp.* 93. *Andrew Melrose Limited, London.* 1954. 5*s. net.*

Plant Respiration, *by W. O. James. Pp.* 281. *Oxford University Press, London.* 1953. 30*s. net.*

CHEMISTRY

Les Applications de la Mécanique Ondulatoire à l'Étude de la Structure des Molécules: Réunions d'Études et de Mises au Point, tenues sous la présidence de Louis de Broglie. *Pp.* 223. *Éditions de la Revue d'Optique Théorique et Instrumentale, Paris.* 1953. *Fcs* 1600 *net.*

The Determination of Crystal Structures, Vol. 3: The Crystalline State, *by H. Lipson and W. Cochran. Pp.* 345. *G. Bell and Sons Limited, London.* 1953. 50*s. net.*

General Chemistry (*2nd ed.*), *by Linus Pauling. Pp.* 710. *W. H. Freeman and Company, San Francisco.* 1953. 51*s. net.*

Industrial Inorganic Analysis, *by Roland S. Young. Pp.* 368. *Chapman and Hall Limited, London.* 1953. 36*s. net.*

Inorganic Syntheses, *Vol. IV. Editor-in-chief John C. Bailar, Jr. Pp.* 218. *McGraw-Hill Book Company Inc., New York.* 1953. 36*s. net.*

Mises au Point de Chimie Analytique Pure et Appliquée (*Première Série*), *edited by J. A. Gautier. Pp.* 172. *Masson et Cie., Paris.* 1953. *Fcs* 1400 *net.*

Nature and Structure of Collagen, *by J. T. Randall. Pp.* 269. *Butterworths Scientific Publications, London; Academic Press Inc., New York.* 1953. 42*s. net.*

Organic Chemistry (5*th ed.*), *by F. Sherwood Taylor. Pp.* 612. *William Heinemann Limited, London.* 1953. 16*s. net.*

Organic Crystals and Molecules, *by J. Monteath Robertson. Pp.* 340. *Cornell University Press, New York; Geoffrey Cumberlege, London.* 1953. 32*s.* 6*d. net.*

Organic Syntheses, Vol. 33, *edited by Charles C. Price. Pp.* 115. *Chapman and Hall Limited, London.* 1953. 28*s. net.*

Physical Constants of Hydrocarbons, Vol. 5, *by G. Egloff. Pp.* 524. *Reinhold Publishing Corporation, New York; Chapman and Hall Limited, London.* 1953. 160*s. net.*

Polarography (*2nd ed. revised*), Vols. I and II, *by I. M. Kolthoff and James J. Lingane. Pp.* 990. *Interscience Publishers, New York and London.* 1953. $11 *and* $12.50 *respectively.*

Starch and its Derivatives (*3rd ed. revised*), Vol. II, *by J. A. Radley. Pp.* 465. *Chapman and Hall Limited, London.* 1953. 65*s. net.*

Structure Reports for 1945–1946, Vol. 10. *General editor A. J. C. Wilson. Pp. viii* + 325. *A. Oosthoek's Uitgevers Mij., Utrecht.* 1953. *Fl.* 45 *net.*

GENERAL

Scientific American Reader. *Pp.* 626. *Simon and Schuster, New York.* 1953. $6 *net.*

Some Aspects of the Conflict between Science and Religion, *by H. H. Price. Pp.* 54. *Cambridge University Press, London.* 1953. 3*s.* 6*d. net.*

GEOGRAPHY

The Climates of the Continents (4*th ed.*), *by W. G. Kendrew. Pp.* 607. *Oxford University Press, London.* 1953. 50*s. net.*

Géographie Mathématique, *by Paul Rossier. Pp.* 198. *Société d'Éditions d'Enseignement Supérieur, Paris.* 1953 *Fcs* 600 *net.*

The Physical Basis of Geography, *by S. C. Chatterji. Pp.* 430. *Ram Narain Lal, Allahabad.* 1953. 8 *rupees net.*

Pioneer Plant Geography, *by W. B. Turrill. Pp.* 267. *Martinus Nijhoff, The Hague.* 1953. *Fl.* 19 *net.*

HISTORY OF SCIENCE

A History of the Sciences, *by S. F. Mason. Pp.* 520. *Routledge and Kegan Paul, Limited, London.* 1953. 28*s. net.*

The Resources of Leonardo da Vinci. *Papers delivered at Southern Illinois University,* 12–15*th November,* 1952, *edited by George Kimball Plochmann. Pp.* 39. *Southern Illinois University, Carbondale, Illinois.* 1953. $1 *net.*

PHARMACOLOGY

British Veterinary Codex, 1953. *Pp.* 737. *The Pharmaceutical Press, London.* 1953. 45*s. net.*

Calendar of the Pharmaceutical Society of Great Britain, 1953–1954. *Pp.* 300. *The Pharmaceutical Press, London.* 1953. 12*s.* 6*d. net.*

Pharmacy and Medicine in Old Edinburgh, *by G. C. Drummond. Pp.* 35. *The Pharmaceutical Press, London.* 1953. 2*s.* 6*d. net.*

PHYSICS

Comptes Rendus du premier Congrès International de Microscopie Électronique, Paris, 1950. *Pp.* 768. *Éditions de la Revue d'Optique Théorique et Instrumentale, Paris.* 1953. *Fcs* 8000 *net.*

Electrical Breakdown of Gases, *by J. M. Meek and J. D. Craggs. Pp.* 507. *Oxford University Press, London.* 1953. 60*s. net.*

Experimental Nuclear Physics, Vol. II, *edited by E. Segrè. Pp.* 600. *John Wiley and Sons Inc., New York; Chapman and Hall Limited, London.* 1953. 96*s. net.*

Flow Properties of Disperse Systems, *by J. J. Hermans. Pp.* 445. *North-Holland Publishing Company, Amsterdam.* 1953. *Fl.* 35 *net.*

An Introduction to Electronics for Physiological Workers, *by I. C. Whitfield. Pp.* 236. *Macmillan and Company Limited, London.* 1953. 18*s. net.*

Mécanique Physique, *by P. Fleury and J. P. Mathieu. Pp.* 439. *Éditions Eyrolles, Paris.* 1953. *Fcs* 2900 *net.*

Nuclear Physics, *by W. Heisenberg. Pp.* 225. *Methuen and Company Limited, London.* 1953. 12*s.* 6*d. net.*

ZOOLOGY

Manuel de Paléontologie Animale, *by Léon Moret. Pp.* 759. *Masson et Cie., Paris.* 1953. *Fcs* 2880 *net.*

Notes on contributors

F. M. BRUCE,
M.Sc., Ph.D., M.I.E.E., A.Inst.P.

Born at Aberdeen in 1912, and educated at King's College, Newcastle-upon-Tyne. Carried out post-graduate research work on precision high-voltage measurement and spark-gap phenomena at King's College, Newcastle, and Queen Mary College, London, with particular reference to the characteristics of the uniform-field spark-gap, for which a detailed calibration for the measurement of high alternating voltages was made. During the war he worked in a Ministry of Supply research department, and afterwards joined the Nelson Research Laboratories of the English Electric Company Limited, where he was in charge of the high-power laboratory. Appointed to the chair of electrical engineering at the Royal Technical College, Glasgow, in 1948.

T. A. STEPHENSON
D.Sc., F.R.S.,

Was born in 1898. After eight years as lecturer in zoology at University College, London, he was in 1930 appointed professor of zoology in the University of Cape Town. In 1941 he took up his present post of professor of zoology at University College, Aberystwyth. He was in charge of the section of the Great Barrier Reef Expedition (1928–9) which studied shore ecology. He has also carried out a biological survey of nearly two thousand miles of the South African coast between tidemarks. In 1946–8 and 1952 he visited North America and Bermuda in order to make further coastal surveys. He has published various papers on sea anemones, culminating in a two-volume monograph on the British species, published in 1928 and 1935; a series of papers on coral biology in the Scientific Reports of the Barrier Reef Expedition, 1931–4; and another on the South African survey. A further series, on the North American coast, is now appearing in the Journal of Ecology. His book 'Seashore Life and Pattern' was published in 1944.

ANNE STEPHENSON

After her marriage with Professor T. A. Stephenson in 1922 was trained by him to act as his research assistant. Was a member of the Great Barrier Reef Expedition of 1928–9, studying the breeding of reef invertebrates; she published a report on this subject in 1934. Was her husband's chief assistant in the ecological survey of the South African coast, 1931–40. Accompanied him to the United States, Canada, and Bermuda as co-worker, and has published joint ecological papers with him.

H. S. W. MASSEY,
B.A., M.Sc., Ph.D., F.R.S.,

Was born in 1908 and was educated at the University High School, Melbourne and Melbourne University. After graduation he undertook research work in atomic physics at the Cavendish Laboratory, Cambridge. In 1933 he was appointed head of the department of mathematical physics at Queen's University, Belfast, and in 1938 became Goldsmid professor of mathematics at University College, London. He held this chair until 1950, when he became Quain Professor and head of the department of physics at the same college. In addition to many papers and reviews in scientific journals he is joint author of the two monographs 'The Theory of Atomic Collisions' (with N. F. Mott) and 'Electronic and Ionic Impact Phenomena' (with E. H. S. Burhop), and has also written two other books.

CHARLES SINGER,
M.D., D.Litt., Hon. D.Sc., F.R.C.P.,

Was born in London in 1876 and studied at University College, London, Magdalen College, Oxford (of which he is now an Honorary Fellow), and Heidelberg. He has been lecturer in the history of biology at Oxford, professor of the history of medicine at London University, and visiting professor of the history of science at the University of California. Among his works are 'A History of Biology,' a 'Short History of Science,' and 'The Earliest Chemical Industry.' With E. J. Holmyard and A. R. Hall he is editing 'A History of Technology' in five volumes. Much of his work has been done with his wife, Dorothea Waley Singer, known for her writings on the philosophy of science, alchemy, and bibliography of early science.

JAMES KENDALL,
M.A., D.Sc., LL.D., F.R.S., P.R.S.E.,

Is professor of chemistry and Dean of the Faculty of Science in the University of Edinburgh. He completes this year his term of office as President of the Royal Society of Edinburgh, the first chemist to hold that distinction. His interest in the aims of the Alembic Club is shown by his books 'Great Discoveries by Young Chemists'; 'Humphry Davy: "Pilot" of Penzance'; and 'Michael Faraday: Man of Simplicity,' all recently published or in course of publication. He was educated at Farnham Grammar School and the University of Edinburgh; he was a post-graduate student at Heidelberg University, the Nobel Institute, Stockholm, and the Technological Institute, St. Petersburg. From 1913 to 1926 he taught at Columbia University, New York.

HERVÉ HARANT,
Docteur-ès-Sciences,

Was born at Paulhan (Hérault) in 1901 and studied at the universities of Strasbourg, Montpellier, and Paris. He became assistant in the Faculty of Science at Montpellier, and then was successively *chef de travaux* in pathological anatomy and *agrégé* of the Faculty of Medicine. He is now professor of natural history, parasitology, and exotic pathology in the Faculty of Medicine at Montpellier, and director of the botanic garden. He has published papers on marine zoology, pathological anatomy, parasitology, epidemiology, botany, and ecology.

KARL K. DARROW,
Ph.D.

Born in 1891. Undergraduate and graduate study at the University of Chicago. Since receiving his doctorate in 1917 he has been continuously with the Bell Telephone Laboratories, New York, except for brief periods as visiting professor at the University of Chicago, Columbia University, Stanford University, and Smith College. His principal occupation has been writing and lecturing on physics and neighbouring sciences. His books are 'Introduction to Contemporary Physics,' 'Electrical Phenomena in Gases,' 'Renaissance of Physics,' and 'Atomic Energy.' He has published numerous papers, mostly of the character of surveys. His lectures on solid-state electronics, given at the University of London in 1953, are about to be published in *Research*. Since 1941 he has been secretary of the American Physical Society.